The Hydroacoustic Assessment of Herring Distribution and Abundance in Barkley Sound, February 18 to March 12, 1982

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ABSTRACT

Taylor, F. H. C. 1983. The hydroacoustic assessment of herring distribution and abundance in Barkley Sound, February 18 to March 12, 1982. Can. Tech. Rep. Fish. Aquat. Sci. 1197: v + 106 p.

The hydroacoustic survey from February 18 to March 12, 1982, showed that herring distribution and abundance in inshore waters immediately prior to spawning was highly dynamic. Herring apparently moved in and out of the Sound as well as from one part to another. The survey only covered the period up to the first wave of spawning. The build-up and second wave of spawning in late March were not covered.

The major spawning grounds are on the northwest side of the Sound. The main access routes were through Felice Channel and to a lesser extent Loudoun Channel and from Imperial Eagle Channel through the Broken Group.

Because of the assumptions that must be made about movement, estimates of total stock size are less reliable than the daily estimates. The hydroacoustic estimate of the amount of herring in the first spawning wave was 12,000-14,000 t compared to an estimate of 11,650 t from spawn survey data. The latter estimate based only on spawning fish would be expected to be smaller than the hydroacoustic estimate which included all herring whether spawning or not.

The surveys showed that useful biomass estimates could be supplied to fishery managers within only hours of the completion of a day's survey. Because the hydroacoustic surveys used calibrated equipment of proven stability and followed a standard pre-arranged grid of track-lines, the results will be more reliable than the echo sounder surveys conducted by the patrol and test fishing vessels. These tended to be spatially and temporally random with the result that some concentrations were overlooked.

Key words: Hydroacoustic, echo integration, Pacific herring, abundance, distribution, spawning grounds.

RÉSUMÉ

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Selon les résultats d'un levé hydroacoustique mené du 18 février au 12 mars 1982, l'abondance et la répartition du hareng dans les eaux côtières juste avant la fraie est très changeante. Il semble que l'espèce entre dans la baie, s'y déplace d'un endroit à l'autre et en sorte. Le levé ne couvre que la période allant jusqu'à la première vague de reproduction; le rassemblement et la deuxième fraie, à la fin de mars, ne sont pas étudiés.

Les principales frayères se trouvent sur le côté nord-est de la baie. Les harengs s'y rendent principalement par le chenal Felice et dans une moindre mesure, par le chenal Loudoun. Ceux entrant par le chenal Imperial Eagle passent entre les îles Broken Group.

À cause des suppositions qu'il faut faire au sujet des déplacements, les estimations de la taille totale du stock sont moins fiables que les évaluations quotidiennes. Selon le levé hydroacoustique de la première vague de reproduction, la quantité de hareng variait de 12 000 à 14 000 t, comparativement à une estimation de 11 650 t effectuée à partir des données sur la fraie. Il est normal que cette dernière, basée uniquement sur le nombre de reproducteurs, soit moins élevée que la première qui regroupe tous les harengs.

L'étude révèle que des estimations utiles de la biomasse peuvent être fournies aux gestionnaires des pêches quelques heures seulement après la réalisation d'un levé quotidien. Les levés hydroacoustiques, qui ont été réalisés à l'aide d'équipement étalonné de stabilité éprouvée, et ont suivi un grillage type prédéterminé de lignes de sonde en route, génèrent des résultats plus sûrs que les levés faits par écho-sondeur par les patrouilleurs et les bateaux de pêche expérimentale. Ces levés tendent à être effectués au hasard dans l'espace et le temps, et certaines concentrations échappent ainsi à l'étude.

Mots-clés: hydroacoustique, sondage acoustique, hareng du Pacifique, abondance, répartition, frayères

INTRODUCTION

Fisheries managers generally require estimates of fish biomass for three reasons: 1) stock-size prediction before the fishery, 2) on-the-spot management immediately before or during the fishery, and 3) the determination of post-fishery escapement.

Since a long lead time is an advantage in stock prediction, hydroacoustic surveys with the purpose of predicting the size of herring (Clupea harengus pallasi) stocks were made offshore in 1980 and 1981 (Taylor and Kieser 1982, and MS 1983). These surveys were carried out in September and November, about 6 months before the roe herring fisheries. The reliability of herring biomass estimates from offshore surveys was affected by a number of mainly biological factors. These included 1) the presence of large stocks of several species of fish in the survey area, thereby introducing problems associated with identifying and separating different stocks, 2) the identity of the stocks contributing to the herring concentrations off the west coast, 3) the determination of the boundaries of herring distribution offshore, and, if possible, of the boundaries of the different contributing populations, and 4) the stage reached in the prespawning migration of each of the major herring populations contributing to the offshore concentrations.

The offshore surveys were followed in February-March, 1982, by an inshore survey of Barkley Sound, described in this report, to estimate stock size immediately prior to the roe herring fishery and to spawning. This survey was planned as a pilot survey to determine if reliable hydroacoustic estimates of herring stocks could be made in relatively confined inshore waters, and if hydroacoustic biomass estimates could be produced sufficiently rapidly to be of value in the tense management situation that occurs where a major fishery takes place in a very short time at very short notice.

The survey also offered an opportunity of comparing the hydroacoustic estimates and estimates made at the same time by totally independent methods — in this case, the divers' spawn deposition survey and the fishery officers' echo sounder survey. Agreement would not validate either method in a comparison if neither has been proved independently to yield an absolute estimate. However, comparison would increase confidence in both, since there is some likelihood that errors and biasses associated with independent methods will not be of the same size and in the same direction.

In offshore waters the survey technique was developed of running a predetermined grid of track-lines that could be added to or deleted from in response to changes in the abundance of fish encountered. It was planned to determine if this technique could be applied in shallow, restricted inshore waters, and if it would locate more effectively the fish concentrations present than the random search technique currently used in the roe test fishing surveys. The survey would also show what technical or biological problems would be encountered and the relative severity of such problems. It was expected that technical problems would not be important, and that reliable estimates of fish biomass beneath the vessel would be quite feasible. The biological problems were not expected to be as complex as those encountered in

offshore surveys. Species other than herring were not expected to be present. The survey area should be readily definable. Short-term migration and movement of herring about the Sound, however, could introduce some problems in the assessment of the total amount of herring present within the Sound.

It is desirable not only to assess the effectiveness of the technique selected but also for effective planning to determine when it can most efficiently be applied so as to yield consistent, reliable results by day or by night. By day, herring would be expected to be aggregated into dense but discrete schools, sometimes widely spread throughout the area. By night, the schools tended to break up, and the herring to form less dense but more widespread layers.

The post-fishery estimation of the escapement of herring does not at present appear necessary nor the application of hydroacoustics to it practical. The fisheries occur either immediately before or during spawning. After spawning, herring move rapidly away from the spawning grounds and offshore, apparently in small, fast-moving schools. If estimates of the spawning stock are available, postspawning stock size would not appear to be of much practical value to management or to population dynamics studies. Reliable estimates of such small, rapidly moving schools dispersed over a wide area offshore (Taylor and Kieser 1982) would be difficult to obtain.

MATERIALS AND METHODS

SURVEY SYSTEM

Vessels

The 101-ft (31 m) table seiner/trawler EASTWARD HO (Capt. G. Sigmund) was chartered for the hydroacoustic survey of Barkley Sound.

An independent survey was carried out by the Department of Fisheries and Oceans patrol vessel COMOX POST and the PACIFIC HARVESTER, a seiner chartered primarily for tagging and for roe test fishing.

Time

The original plans for the survey called for a charter of 40 days between February 1st and March 19, 1982. plus an optional extension of up to 10 days. This plan was later modified to conform to the standard period of 28 days for roe test fishing charters. The charter period was therefore changed to February 15 to March 14, with provision for up to 15 days' extension (to March 29).

In Barkley Sound, the herring stock built up in early March; and the first wave of spawning occurred from March 7 to 10. There were then virtually no herring in the Sound until late on March 12. The concentration located at that time contributed to a permit fishery of 544 t[1] mainly on March 13[2]; and a commercial fishery of 3080 t on March 17-18. It also led to the second wave of spawning from March 24-30.

Instructions were received on March 12 that all charters were to be terminated after 28 days in order to reduce the permit catch (for charter payment) from what appeared to some at the time to be a very depressed stock. This charter had to be terminated immediately since time had to be allowed for travel to and from Nanaimo, and for loading and unloading equipment. Thus, the charter covered only the build-up and first wave of spawning in Barkley Sound. The build-up for and the second wave of spawning was not covered.

Area

The survey area covered all of Barkley Sound and Trevor Channel including an area extending 4 nautical miles seaward to beyond the 100-m contour from Folger Island to Chrow Island. For convenience, the whole area was divided into a number of regions (Fig. 1). Place names referred to in the text are also shown on Fig. 1 and on Fig. 2.

A system of rectangular track-lines (Fig. 2) was set up to cover the survey area in a systematic manner. The spacing between track-lines varied with the importance of the area as a herring spawning ground, and with its topography. In areas where herring were unlikely to concentrate, for example outside the Sound, track-lines were spaced 1.0 to 1.5 nautical miles apart. In areas where herring concentrations occurred, spacing was 0.25 to 0.5 nautical miles apart. In narrow channels topography determined the spacing. In Trevor Channel, the track-lines followed a double zig-zag pattern.

Mode

To cover the complete series of track-lines required 3 or 4 days at a survey speed of 9 kn. In practice, more attention was paid to those areas where herring were known to concentrate. Areas unlikely to contain herring were covered at irregular intervals. Such areas were the inner part of Imperial Eagle Channel, Trevor Channel, and part of the Sound seawards of Chrow Island to Folger Island. At the peak of the survey, some important areas, such as Newcombe Channel, were covered every other night.

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[1]All catches and biomass estimates are in metric tons of 1000 kg or 2205 lb.

[2]The dates of the permit fishery were taken from the report by the fishery officer aboard the roe test fishing and tagging seiner, PACIFIC HARVESTER.

Track-lines were run both by day and night. Where possible, the same area was surveyed in consecutive periods. Day surveys were usually between 0700 or 0800 hrs and 1200 or 1400 hrs, night surveys between 1700 or 1800 hrs and midnight or 0200 hrs. Each survey was followed by a 1- to 2-hour data processing period. Longer surveys were avoided if possible, because of the strain imposed on the skipper by navigating at 9 kn among the narrow channels, shallows and reefs of the area, and also because at night the layer tended to disperse after midnight. A schedule of operations (Table 1) shows the times of the surveys, the areas covered, and the track-lines included.

INTEGRATION SYSTEM

The echo sounding and echo integration system was similar to that used by the G.B. REED on the offshore cruises (Taylor and Kieser 1980). The main difference was that the 15- × 30-cm ceramic transducer was used either in a torpedo-shaped towed body or in a ladder mounting secured amidships on the port side. Both mountings introduced relatively little noise. The ladder mounting was preferred when navigating in confined areas. The towed body was used only in open-ocean areas to minimize the effect of waves. The ladder held the transducer level approximately 2.5 m below the surface. A reflection from the hull appeared beginning at about 4 m, but not deep enough to interfere with integration. Lowering the ladder removed this echo, but resulted in excessive vibration in the mounting.

INTEGRATION DATA PROCESSING

The output of the echo integrator is proportional to the average echo-intensity ($\overline{I}_{mn}$) taken over the m^{th} depth interval and n consecutive transmissions. It is given by the following equation, where all terms are in decibels[3].

$$\overline{I}_{mn} = TL + \overline{TS} + VR + SL + R100 + BW + \Psi + CTAU + \overline{RO}_{mn}.$$

The terms on the right in order are: transmit level, average target strength, voltage response, shell loss on transmission and reception from the towed body cover, TVG reference depth factor, band width, beam factor, depth slice ($10 \log \frac{cT}{2}$ or Δr), and average volume density in kilograms, rather than in numbers of fish. By rearranging the terms, the equation can be solved for $\overline{RO}_{mn}$ since all the terms then on the right-hand side, including $\overline{TS}$, are known (Appendix 1). Taylor and Kieser (1980, Appendix 1) give a more detailed discussion of these terms.

The returned echoes were integrated over a distance of 0.5 nautical mile, and for depth intervals of 0-5 m, 5-7.5 m, 7.5-10 m, 10-15 m, and

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[3]A decibel is 10 times the logarithm of an intensity ratio.

15-20 m, then by 10-m intervals to 150 m, and by 25-m intervals from 150 to 300 m. Surface and hull reflections were isolated in the narrow 5- to 7.5-m and 7.5- to 10-m depth intervals, thereby facilitating their exclusion from future calculations. In processing the data, a single depth stratum was used, usually from 10-60 m (5-33 fath). Echosounder records showed that all fish schools above 60 m were most probably herring, except in certain limited areas on some surveys where some small schools may have been rockfish. Test fishing by seine for roe development and for tagging confirmed that the schools above 60 m were herring. An exception was off near Seapool Rocks in Trevor Channel where the concentration proved to be mainly northern anchovy (Engraulis mordax mordax). If near-surface schools occurred, one or more of the shallow depth intervals, 0-5 m, 5-7.5 m, and 7.5-10 m, were included in the integration calculations as required. Little herring was found below 60 m. In the deeper water of some areas (Trevor Channel and Imperial Eagle Channel) the 60-m boundary did exclude some other pelagic fish, such as dogfish (Squalus acanthias), hake (Merluccius productus) or pollock (Theragra chalcogramma).

Since all schools above 60 m appeared to be adult herring, no analyses for species and size compositions were required. At the first stage of computation, a single value for target strength representative of adult herring (Appendix 1) can thus be entered in the above equation along with the values of other constant and known factors.

A computer program (in BASIC) was used to obtain the average intensity in each of the depth intervals, and from them the average intensity for the major depth stratum. The TVG correction factor for each depth interval, if required, is entered in this program, as also are the remaining factors, which are all independent of depth. The program computes both average density in kilograms per unit volume and average density in kilograms per unit surface area[4]-i.e. area density. This latter value is plotted for each print-out interval along the track-line, and is contoured at intervals of powers of 10.

The charts (Fig. 3-30) resulting from plotting the area densities from each day and night survey are the basis of the estimates of herring biomass. These charts show 3 contours at 0.1×10^{-2} kg/m^2, 0.1×10^{-1} kg/m^2, and 0.1×10^{0} kg/m^2. The last represents the lower boundary of major concentrations; while the first represents the lower boundary for recognition of herring as individuals or very small schools. The product of the area within a contour boundary and the average surface density is the total amount of herring in metric tons for that area or concentration. These quantities can then be summed to give the total biomass of herring for that survey.

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[4]Density in kilograms per unit surface area is the product of fish density in kilograms per unit volume and average depth of the stratum.

RESULTS

HERRING DENSITY

Average surface rather than volume density is used throughout this report. Density is expressed in a variation of the scientific notation (the E has been omitted), for example 0.235+1 kg/m^2 is 0.235E+ 1 kg/m^2 or 2.35 kg/m^2 and 0.563-3 kg/m^2 is 0.563E-3 kg/m^2 or 0.000563 kg/m^2. Since the density values used are averaged over the length of track-line covered in a print-out interval (usually 0.5 nautical mile), they will be very much smaller than the average density in the water column (usually 10 m to 60 m). Such values in turn will be much smaller than the actual density within the school.

By day, herring were in dense discrete schools. By night, the schools tended to spread out to form layers usually in the upper part of the water column, frequently at a depth of 15 to 30 m.

By day, surface area densities ranged from values with an exponent of +1 down to values with an exponent of -5, a range of one million times. However, only values with an exponent of -2 or greater (Fig. 31A-C) were considered to represent herring. Values with an exponent of -2 (Fig. 31D-E) represented small scattered schools, or single fish which, while they indicated herring were present, did not contribute appreciably to the total biomass. Values with an exponent of -1 (Fig. 31C) represented small schools or a broken up layer. These usually occurred on the edges of the main concentration and did not cover an appreciable area. Values with an exponent less than -2 (Fig. 32 A & B) were considered due to scattered plankton or random noise. Schools with a density exponent of +1 (Fig. 31A) not only showed considerable white-lining within the school but also showed extensive reverberation extending to below the bottom. Such reverberations may indicate that the relationship between signal intensity and fish density is not linear at these high values. Biomass corresponding to such values may be underestimated. The slight reverberation from schools where the density exponent is +0 (Fig. 31B) would be integrated, but would be unlikely to produce an appreciable effect on biomass.

At night, surface area densities ranged from values with an exponent of +2 down to those with a value of -4, again a range of a million times. As in the daytime, density values with an exponent of less than -2 (Fig. 32D, E) were considered to represent insignificant amounts of fish, scattered plankton, or random noise. Values with an exponent greater than +0 (Fig. 33A-C) represented a major concentration of herring as they did by day; values with an exponent of -1, (Fig. 33D) a layer starting to break up, and values of -2, a layer of scattered single fish (Fig. 33E). Although high average density values were more common at night because of the greater horizontal and vertical extent of the layer (within the integration interval), the actual densities of the nighttime layers were less than the actual densities of the daytime schools. At night, white-lining was not apparent in schools where the exponent was +0, but was detectable at densities of +1 (Fig. 33B and C). However, by day, schools when the exponent of the average density was +0 showed noticeable white-lining, (Fig. 31B), and schools with an

exponent of +1 strong white-lining (Fig. 31A). Similarily, at night, layers with an exponent of +1 showed little or no reverberation (Fig. 33B) while by day schools with this exponent showed strong reverberation (Fig. 31A). At night, reverberation was only a factor when the exponent was +2 (Fig. 33A). Thus, only at those highest values was biomass likely to be underestimated.

Thus, both by day and at night, density values with an exponent of +0 or greater denote the presence of a substantial concentration of herring. Density values with an exponent of less than -2 indicate that fish, if present, occur in trace amounts, usually as scattered individuals. Densities with exponents between -2 and +0 while denoting the presence of increasing quantities of herring do not indicate the presence of a major concentration. As the values increase, the echograms take on the characteristic appearance of herring schools or layers.

DISTRIBUTION AND BIOMASS

Day vs night surveys

The schooling patterns by day (Fig. 3-16) and by night (Fig. 17-30) are different. For this reason, it is preferable to base the discussion of distribution and biomass on the results obtained at one period of the day. The night survey results will be used primarily.

By day, herring are in dense, discrete schools, whereas by night they form more extensive but generally somewhat less dense layers. The former may perhaps introduce a greater element of uncertainty in the sampling, in that the small schools are more likely to be missed than a widespread layer. In addition, the greater density of the daytime schools occasionally introduced two effects that could lead to underestimation of biomass. In one or two instances, school density was great enough to produce reverberation (Fig. 31A) and may also have exceeded the limit of the linear relationship of density and voltage return. The reverberation was sustained long enough so that it extended beyond the integration depth range. Also, on a number of occasions during the day, the voltage returned by the schools exceeded the upper limit of the input voltage to the integrator. While gain adjustment will correct the affect of the latter, no compensation can be made for reverberation. Although at times at night density was great enough to exceed the input voltage limit, it was not great enough to produce reverberation.

The day and night biomass estimates (Tables 2 & 3) did agree reasonably well on some (4) occasions, (Feb. 19, 20, 21, and 27). However, on the majority of occasions (9) differences existed. These differences, arising from larger nighttime than daytime estimates, in most cases were so great that they are more likely attributable to movement of the stock than to sampling problems. In the first part of the season (to March 2) they probably resulted from movement of herring into the area, in the latter part of the season (from March 7), out of the area. On the other hand, small differences coupled with small biomass estimates may well be the result of sampling error.

Distribution and biomass

The results of the night surveys (Table 3 and Fig. 17-30) show that in 1982 herring distribution was in a highly dynamic state in Barkley Sound prior to spawning. There was extensive movement not only between areas within the Sound, but also into and apparently out of the Sound.

It was found throughout the survey that if herring were present in larger numbers (over 1000 t a night) most tended to occur in dense aggregations (density exponent of 0 to 2). The medium and low intensity aggregations (density exponent of -1 and -2, respectively), although covering extensive areas, contributed relatively little to the biomass total (Table 4). Near spawning time, if large concentrations were present there were more herring at medium intensities, and over a wider area than earlier in the season. When small quantities of fish occurred, they tended to be spread at medium and low density levels (density exponent of -1 and -2) over a wide area. However, late in the season more small dense concentrations occurred than earlier.

On the night of February 18 (Fig. 17), about 2200 t of herring were found on the northwest side[5] of Barkley Sound. Of this amount, about 1,400 t occurred off Lyall Point. Smaller amounts were located in the Stopper Islands area (380 t), in Toquart Bay (107 t), and in the Brabant Islands/Peacock Channel area. The following day the tonnage (Table 2 and Fig. 4) was about the same (1,959 t) with 1,212 t off Lyall Point. The quantities in Toquart Bay, around the Stopper Islands and in the Brabant Island/Peacock Channel area had declined (106 t, a trace, and 88 t, respectively). However, about 500 t were located off Chrow Island, an area not surveyed the previous evening.

Part of the area was next surveyed on the night of February 22 (Fig. 20), and the remainder on the night of February 24 (Fig. 22). On February 22, 10,877 t of a total for the night of 11,059 t were located from Chrow Island almost to Forbes Island. About another 100 t lay just south of Forbes Island. In the remainder of the area surveyed only scattered herring were located. On the night of February 24, only 319 t were located in Peacock, Sechart, and David Channels and Toquart Bay. The herring were scattered with the exception of a small concentration (179 t) off Lyall Point.

By day on February 22, only 3,833 t of herring had been found from Felice Channel to Forbes Island (Fig. 7 and Table 2) in two major concentrations, 2,009 t in Newcombe Channel, and 1,673 t in Felice Channel. There was a small concentration of 142 t off Forbes Island. Herring schools were also sighted by trawlers operating on the edges of the banks west and south of the Felice Channel area. It is possible that on February 22 herring were moving rapidly through Felice Channel into Newcombe Channel. During the day survey on February 24, the Newcombe Channel area was covered (Fig. 8), complementing the area surveyed at night (Sechart Channel to Mayne Bay). Only 619 mt were located, mainly in one relatively small concentration off Chrow Island. These surveys show that the large body of herring present in Newcombe Channel on February 22 had left the area by February 24.

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[5]This region, often referred to as Barkley Sound West, includes all areas between the Broken Group and the northwest shore of the Sound.

On the next survey of Forbes Island, Brabant Island, Peacock, Sechart and David Channels on February 26, only 388 t of herring were located, scattered throughout the area; and on the next survey of Newcombe Channel on February 27, only 290 t were found.

The daytime surveys on these two dates covered the same areas as the night surveys. The distributions (Fig. 9 and 10) and amounts of herring found were somewhat similar.

On February 28 the Felice and Loudoun Channel areas and the outer part of Newcombe Channel were surveyed. At night, about 1,477 t were located, mainly in a single concentration (1,280 t) outside Starlight Reef (Fig. 25). The day survey covered the same area. While the distribution pattern was similar (Fig. 11), the biomass (551 t) was smaller. Few herring were in Newcombe Channel, 166 t during the day, and 138 t at night.

On March 2, the northwest side of the Sound was again surveyed. Although by day, only 963 t were recorded in small concentrations in Felice Channel, near Chrow Island, and near Forbes Island (Fig. 12), at night 4,983 t were found, mainly in one large concentration in Newcombe Channel from Chrow Island to Forbes Island (Fig. 26). Throughout the remainder of the area north to Lyall Point only scattered herring occurred.

The northwest side of the Sound was next surveyed on the night of March 7, the day of March 8, and for the final time on the night of March 9. The night survey of March 7 covered the entire area with the exception of Felice Channel and Toquart Bay (Fig. 28). About 7,389 t of herring were located. The main concentration extended from Newcombe Channel into Macoah Passage. There was about 3,954 t in the former locality, 524 t off Forbes Island and about 948 t in Macoah Passage. Other concentrations occurred off Lyall Point (637 t), in Loudoun Channel (826 t) and in the Brabant Island area (308 t). While most of the herring occurred in the dense Newcombe Channel concentration, the herring were more widely distributed at intermediate densities than previously. During the day survey on March 8, only 4,012 t were located, mainly in the Newcombe Channel area (Fig. 15). Loudoun Channel was not covered. The final survey of the northwest side of the Sound on the night of March 9 covered Newcombe Channel, the Forbes and Stopper Islands areas and David Channel (Fig. 30). The total amount of herring found was 1,766 t, mostly in David Channel (1,116 t). As on March 7, dense concentrations were less in evidence; the distribution was characterized by widespread layers of intermediate density. Although the area was searched intensively for herring to fish by both the EASTWARD HO and the PACIFIC HARVESTER, no concentrations were found from March 9 to March 12, when second wave spawners started to appear.

Major concentrations of herring were also encountered in the outer part of Imperial Eagle Channel. This area was first surveyed on February 20; by day and by night. The total herring biomass in the area at night was estimated to be 886 t. Relatively small concentrations (Fig. 18) were found along the west side from Effingham Island to Village Reef, in the center of the channel between this reef and Satellite Passage, and along the east side from Folger Island to Satellite Passage. There were also smaller concentrations along the west side and in the center to Swale Rock. The

daytime estimate was similar (822 t). The distribution pattern (Fig. 5) was the same as at night, although the herring were grouped into a number of separate schools.

Because of an equipment failure from March 3 to 5, this area was not surveyed again until March 6. However, the area was kept under observation by both the COMOX POST and the PACIFIC HARVESTER. Their reports (Table 7) show this amount of herring built up from March 3, reached a peak on March 5 and 6 and declined sharply thereafter. On night of March 6, a hydroacoustic survey provided an estimate of 6,919 t, mainly in the area from Miller Reef around Effingham Island and into Coaster Channel (Fig. 27). Herring were lightly distributed over most of the area surveyed. The daytime estimate on March 6 was only 1,285 t. The pattern of distribution (Fig. 13) was, however, similar to the nighttime pattern, except that the herring were in isolated schools rather than in an extensive layer.

A third survey of the area was conducted on the night of March 8. The amount of herring present had decreased sharply to 2,281 t. The main concentration lay along the west side of Imperial Eagle Channel in Coaster Channel and off Village Reef (Fig. 29). This concentration could be traced at lower and decreasing densities across to Satellite Passage. Another small concentration occurred off Folger Island. The decrease in amounts and the distribution pattern found on March 8 suggest that herring had moved out of the area, perhaps through Coaster Channel. In the daytime survey on March 9, about 1,099 t were found, mainly in a small concentration in mid-channel off Effingham Island (Fig. 16).

Besides the two major areas of Barkley Sound West and the outer part of Imperial Eagle Channel, Trevor Channel, the inner part of Imperial Eagle Channel, and the area outside Imperial Eagle Channel and the Broken Group of islands were surveyed on occasion. Trevor Channel was surveyed on Feb. 21 by day and by night following the report by the patrol vessel of a large concentration of herring there. At night, 1,309 t of fish were located. Of these, 1,162 t were concentrated between Seapool Rocks and Bamfield Inlet (Fig. 19). Test fishing showed this concentration to be 70% northern anchovy, 20% juvenile herring, and 10% adult herring. Scattered fish were found throughout the rest of the channel. From the depth distribution and appearance on the sounder paper these were assumed to be hake or pollock. A midwater trawl haul (HB81-19) in March, 1981, in the same area yielded 246 kg of hake and 318 kg of dogfish (McCarter, Barner, and Taylor 1982). On the day survey, almost the same quantity was found (1,918 t); the distribution was also similar (Fig. 6). A second survey on March 12 was interrupted after covering only the first legs at the northern end of the channel. The inner part of Imperial Eagle Channel from Swale Rock to Vernon Bay was surveyed during the day on February 18. Only 39 t of herring were located, widely scattered along the western shore. The area seaward of Barkley Sound from Folger Island to Loudoun Channel was surveyed on the night of February 23 (Fig. 21) and during the day of March 7 (Fig. 14). Only scattered fish were located. These could have been either rockfish or herring. On February 23, the estimated biomass was 55 t; on March 7, 138 t. In addition, on the latter survey 220 t of herring were found off Loudoun Channel, and 479 t in Felice Channel.

In review, herring which spawned mainly in the northwest part of Barkley Sound, in 1982, apparently approached from offshore along two paths. The first is directly through Felice Channel and to a lesser extent Loudoun Channel; the second from Imperial Eagle Channel probably through Coaster Channel and the other channels of the Broken Group. In the early part of the season, herring were not present in inshore waters near the spawning grounds for protracted periods. On February 18, a sizable body of herring (2,209 t) was present in the inner part of the area from Peacock Channel to Toquart Bay. This body was not located again and must have moved out of the area. There were no reports of spawning. There was then little evidence of herring until February 22, when a large concentration (11,059 t) was found in Newcombe Channel. This influx coincided with the period of high tides associated with the new moon. This body must also have moved out of the Sound without spawning since (from February 24 to 27) surveys revealed little herring in the areas (300 to 400 t). The first wave of spawning occurred from March 7 to 10, during the period of increasing tidal height associated with the full moon. The build-up began about March 2, when a large quantity of herring (4,983 t) appeared in Newcombe Channel. Two days previously, 1,309 t had been located outside Barkley Sound proper to the southeast of Chrow Island. By March 7, when large scale spawning had began, the quantity had increased to 7,389 t and the herring had become somewhat more generally distributed. No large concentrations of herring were found in Imperial Eagle Channel until March 4 and 5, when the test fishing vessel located 3,628-4,535 t. On March 6, this concentration was estimated to contain 6,919 t. After March 7, the quantity of herring on the northwest side of the Sound declined rapidly. On the morning of March 8, there were estimated to be 4,012 t there and on the evening of March 9, 1,766 t. No herring were found thereafter until March 12, after the termination of the survey. The herring that were in Imperial Eagle Channel on March 6 either moved out or, more probably, moved rapidly across to the northwest side, for by the night of March 8 only 2,281 t remained in Imperial Eagle Channel and on the morning of March 9 only 1,099 t.

Total biomass of herring (to March 10)

Although the estimates of the quantity of herring encountered on the individual surveys are probably reasonably accurate, estimates of the total amount of herring in the first spawning wave to Barkley Sound will be less accurate as they involve assumptions about stock movement.

Returns (Table 5) from the 1982 Barkley Sound tagging program (Haegele 1982) show that some herring moved to Clayoquot Sound (Area 24) and a few as far as Nootka Sound (Area 25). Unfortunately, all tagging was done before the first wave of spawning in Barkley Sound occurred, but no recoveries were made until after this wave had spawned and left. Based on the combined permit and seine fisheries recoveries only, the tag returns suggest that approximately twice as many herring remained to spawn in the second wave as moved to other areas. However, no estimate can be made of the proportion that spawned in the first wave or how this proportion compared to the proportions that left the area or spawned in the second wave.

While the assumptions that must be made about stock movement appear entirely reasonable, they cannot be substantiated. Several estimates can be made depending on what assumptions are made.

a) If it is assumed that all herring on the northwest side of the Sound spawn there, and are distinct from those found in Imperial Eagle Channel on March 6, all of which eventually migrated to the northwest side, the total estimate is 7,389 + 6,919 or 14,308 t.

b) If it is assumed that all the herring in Imperial Eagle Channel on March 6 did not move across to the northwest side and spawn in the first wave, a somewhat lower estimate results. This estimate is 7,389 + (6,919-2,281) or 12,027 t.

c) Still other and lower estimates result if it is assumed that the 1,766 t found in Barkley Sound on March 9 did not spawn in the first wave. This results in estimates of (7,389-1,766) + 6,919 or 12,542 t and of (7,389-1,766) + (6,919-2,281) or 10,261 t. Estimates intermediate in value to the foregoing will result if it is assumed the estimate for the day survey of March 9 (1,099 t) represents the quantity of herring from Imperial Eagle Channel that did not move to the northwest side of the sound to spawn. This value replaces the estimate of 2281 t and in (b) and (c). The results would be 13,209 t and 11,443 t, respectively.

The foregoing estimates all contain the basic assumptions that the only immigration to the northwest side after March 7 was from Imperial Eagle Channel, that no further immigration occurred through Felice or Loudoun Channels, and that no further immigration into Imperial Eagle Channel occurred after March 6. If such immigration did occur, both series of estimates would underestimate the actual size of the first wave spawning stock. Conversely, it is quite possible that all herring in Barkley Sound at this time did not spawn in the first wave. The estimates may thus overestimate the actual size of the first spawning wave. Since some herring may well have migrated into the northwest part of Barkley Sound after March 7, and into Imperial Eagle Channel after March 6, and since not all herring in the sound may have spawned in the first wave, the best estimate of the size of this wave is probably between 12,000 and 14,000 t. The best estimate of the number of herring in the Sound at the time would be nearer the upper limit.

RELIABILITY OF ESTIMATES

Taylor and Kieser (1982) pointed out that the accuracy and precision of hydroacoustic estimates will depend on the variance of the density estimates and on the extent to which certain basic assumptions are met. These assumptions are:

a) that calibration is accurate, and the system stable;

b) that target strength values used accurately represent the actual *in situ* values;

c) that the species composition of each concentration is accurately estimated;

d) that all the herring concentrations are fully "visible" to the sounder, and lie within the systems operating range;

e) that the whole of the stock is available for survey.

Fiedler (1978) provides an expanded but essentially similar list. In addition to "patchiness" of school distribution, he suggests 9 possible sources of error which may be important in acoustic surveys. They are:

1. The effect of varying hydrographic conditions on the acoustic signal.

2. Unschooled fish and small schools were not detected.

3. Blocking of signals to and from fish far from the ship by fish nearer the ship.

4. Inability to survey in shallow water.

5. Fish in the top surface layer are missed by the beam.

6. Movement of schools relative to the survey grid.

7. Vessel avoidance.

8. Errors in the factor for conversion of acoustic signal information to a biomass estimate.

9. Failure to discriminate between schools of different species.

Fiedler's factors refer particularly to echo ranging surveys (horizontal sounding) for surface schooling species, such as the northern anchovy off California or the Peruvian anchoveta, rather than echo sounding surveys (vertical sounding) applied to deeper swimming pelagic species. Some of the factors will thus be of less significance in echo sounder surveys.

1. The effect of varying hydrographic conditions on the acoustic signal is of comparatively small importance in echo sounding. However, in echo ranging, changes in water temperature and in salinity are important factors curving the beam upwards or downwards.

2. Unschooled fish and small schools are readily detectable at the gain settings used and over the shorter ranges usually encountered in echo sounder surveys.

3. Blocking of signals to and from fish far from the ship by fish nearer the ship is again a more serious problem in echo ranging than in echo sounding. In the Barkley Sound survey, some blocking in the form of reverberation, or the scattering of the signal by fish packed in a dense school, was observed, but only on one or two occasions. It was not considered to be an important source of error.

4. Inability to survey in shallow water is probably again a more important source of error in echo ranging than in echo sounding. In the

latter, minimum depth depends on the depth of the transducer and the suppression depth of the receiver (using 5 m); in echo ranging it also depends on the depth of the transducer and in addition on the beam and tilt angles. Water depth did not constitute a limiting factor in the Barkley Sound surveys.

5. In both echo ranging and echo sounding, fish in the top surface layer will be missed by the acoustic beam. In echo sounding fish above the depth of the transducer plus the suppression distance would be missed. In Barkley Sound this was about 7 m. In only a few instances did the echo sounder records indicate that the tops of schools may have been about this depth.

Thus, of the 9 factors listed by Fiedler, 5 do not appear as major sources of error in the Barkley Sound Survey. The remaining four factors correspond with those discussed by Taylor and Kieser (1982) for the offshore surveys with the exception of one factor.

6. The movement of schools relative to the survey grid. In discussing the offshore surveys, this factor was not specifically considered as fully as it should. In Barkley Sound, herring were obviously moving about the Sound as well as in and out of it. What is not clear is the extent they moved during a particular day or night survey. However, no evidence of pronounced movement within an individual survey was detected. A school or layer located on one transect was found in the same area as successive transects that cut the school.

Movement relative to the survey grid might be expected to be less when herring were spread out in a layer at night, than by day when they were densely schooled. Keeping the length of the transects short, and running them in the same direction as any suspected movement would minimize the effect of this factor. In most areas, transects required less than an hour to run.

7. Vessel avoidance. There is no information on whether herring actively avoid an approaching vessel from either the offshore or Barkley Sound surveys. However, Olsen (1979, 1980) has shown that herring in the Norwegian fjords tend both to dive and to move to the side as a vessel approaches. This may be a source of error in B.C. herring biomass estimates and calls for early investigation. It might be expected to be more important inshore than offshore where herring are in deep water (70-100 m). However, no obvious instances of vessel avoidance were observed in Barkley Sound.

The sources of error discussed so far, excluding the first and the sixth, suggest that nearly all the herring were fully "visible" to the sounder and that subjectively this assumption is probably met. The major dense concentrations which contain the bulk of the fish were all within the boundaries of the survey. At times, track-lines were extended, or additional track-lines added to ensure that the boundaries of major concentrations were defined. Migration in and out of Barkley Sound and between different parts of the Sound occurred and complicated the interpretation of the total amount of fish spawning in the first wave. However, such migration would not be a major factor in the estimation of the amount in any individual concentration or on any individual survey. The bias introduced by these factors is thus probably small. Vessel avoidance, however, could be a more serious source of error and should be investigated.

8. Calibration and target strength. Calibration, now carried out by the Applied Physics Laboratory, University of Washington, is considered satisfactory and at least at the "state-of-the-art" level. Calibrations (Appendix 1) are considered accurate to +0.5 dB. All components of the system have proved to be stable over several years of operation.

Target strength is the major "scaling factor" in hydroacoustic estimates. It is a complex factor dependent on the morphology, behavior, depth, and depth accommodation history of the fish. For herring, a value of -32.0 dB, rounded from a calculated value of -31.5 dB (Taylor and Kieser 1980) has been used. A subjective estimate suggests that, while target strength values for fish with air bladders calculated in the way proposed may well have an effect on biomass that is consistent from trip to trip, the effect, especially for physoclystous fish (fish with closed air bladders), could result in a bias of +1 or even 2 dB. For herring, the bias may well be less. Edwards (1980) obtained the same value (-31.5 dB) from measurements on caged herring. He also showed that the effect of changes in depth were unexpectedly small for the physostomous clupeids (with a ducted air bladder) in comparison to those for the physoclystous gadoids.

The bias introduced by this factor may thus be less than originally considered likely.

9. Failure to discriminate between schools of different species. It is not always possible to distinguish between herring schools and those of other pelagic fish by the appearance of the echosounder records. Some species, such as hake and pollock, can be distinguished in this manner in most cases, and the areas containing such schools isolated. Other species, such as pelagic rockfish and dogfish, are difficult to distinguish from herring by the appearance of the echosounder records. In these instances, net hauls (midwater trawl hauls) must be used to determine the species composition in the area, and the integrated signals proportioned accordingly. The accuracy with which the midwater trawl catches represent the actual species composition will be reflected in the accuracy of the biomass estimates. The determination of species composition may be the major or one of two major sources of error in hydroacoustic biomass estimates. Its importance will depend on the degree to which the species can be identified from echosounder records, the number of pelagic species in the depth zone or area of interest, and the extent to which reliance must be placed on results from test fishing. In the Barkley Sound survey, species composition was not considered a major source of error. All schools or layers encountered down to 60 m appeared from sounder recordings to be typical herring formations. Seining for tagging and testing for roe maturity confirmed this. One exception was in Trevor Channel, where fishing showed 70% of a large concentration was northern anchovy. Hake and pollock were present in small numbers in the deep water of the same channel.

The bias introduced by the previous factor, calibration, and target strength may be less than originally considered likely. The bias introduced by species composition is probably small in the Barkley Sound survey.

It is interesting to note that of the 4 major and 5 minor sources of error discussed, only one major source (point 8) and perhaps 2 of the minor sources (points 1 and 3) are specific to hydroacoustic estimation. The others apply equally well to any other method of estimation involving vessel

operation or fishing. It also appears that of the 4 major sources of error, two (points 9 and 6) will obviously have to be determined for each investigation. The other two (points 8 and 7) may well also have to be determined each time. Target strength (point 8) will depend on species, and certainly for physoclystous fish on depth; vessel avoidance (point 7) will also depend on species and depth and also perhaps on behavior in relation to spawning or feeding activities. The degrees of importance of the 5 less important sources (points 1 to 5) are all likely to vary from survey to survey.

The amount of error associated with the biomass estimates will not only depend on the extent to which the foregoing basic assumptions are met, but also on the variance of the density estimates. Taylor and Kieser (1982) have pointed out that although hydroacoustic measurements yield a large number of observations whose analysis should lead to a valid estimate of variance, it has proved difficult to find a satisfactory model to accomplish this. The reason is observations are not taken randomly but are made serially along a predetermined regular grid of track-lines. In this survey the determination of variance is further complicated by the desirability of contouring the fish concentrations. Contouring -- grouping data points of similar value -- will reduce the variance. The lowest contour interval, 0.1×10^{-2}, was introduced to mark the boundary above which echoes are recognizable as herring. An upper interval was introduced (0.1×10^{0}) since 90% of the herring obviously occurred in concentrations with densities above 0.1×10^{0}. The intervening interval (0.1×10^{-1}) did not differentiate clearly between a concentration and dispersed fish.

Taylor and Kieser (1982) calculated variance by three methods -- the random sample method based on the assumption of normal distribution (Forbes and Nakken 1972), Bayley and Hammersley's (1948) auto-correlation method, and Hansen, Hurwitz and Madow's (1953) method of cluster analyses. None of these methods provided a model which reasonably fitted the data or their method of acquisition. None filled properly the basic underlying assumptions. It was considered that the simplest method, Forbes and Nakken's, may have some limited value in that it is relatively straightforward to calculate and likely provided as reasonable an estimate as any of the probable level of variance even though not of its actual value.

This method was applied in estimating the variance of those nighttime concentrations of greater than 1,000 t (Table 6). The relative variance ranged between 12 and 47% for those sections of the concentrations with density values above 0.1×10^{0}. The high values occurred in the densest concentrations where the range in density was over 100 times, and least where the range in density was less than 10 times. The inclusion of those parts of the concentration with lower density values (0.1×10^{-1} or 0.1×10^{-2}) tended to increase the relative variance estimates somewhat. When values down to 0.1×10^{-1} were included the relative variance ranged from 16 to 50%, and when values down to 0.1×10^{-2} were included the range was the same, although most individual values tended to be larger.

COMPARISON OF ESTIMATES BY DIFFERENT METHODS

It is valuable to compare estimates of the same parameter by different methods. Such comparisons will not prove the correctness of any of the estimates unless one of the methods has previously, independently been shown to yield absolute estimates. If the estimates compared are close, the comparison may increase the degree of confidence in both for there is some likelihood that independent estimates will not be biased to the same extent in the same direction.

There are two series of independent estimates to which the hydroacoustic estimates can be compared. There are estimates of the daily amounts in different parts of the area resulting from echosounder surveys conducted by the fishery patrol vessel and by the roe test fishery vessel, and the estimation of the total size of the spawning stock (in the first wave of spawners only) derived from the divers' spawn surveys.

Pacific Biological Station Divers' Survey

The hydroacoustic estimate of the total amount of herring in the first wave of Barkley Sound spawners can be compared to the estimate derived from the divers' spawn survey. The latter amounted to 11,650 t, derived by converting the estimate in terms of eggs deposited using the average factor of 10^8 eggs per short ton of herring and adjusting to metric tons. The hydroacoustic estimate lay between 10,261 and 14,308 t depending on the assumptions made about migration. The most likely estimate was considered to be between 12,000 and 14,000 t. The estimates are satisfactorily close and certainly well within the probable limits of error for the hydroacoustic estimates. Limits to the spawn deposition estimate have not been derived. The hydroacoustic estimate should be somewhat greater than the spawn deposition estimate. The latter includes only fish that have actually spawned while the former estimates the fish present on the grounds. It may thus contain an element of fish that were on the grounds but would not spawn until a later wave.

Management echo sounder surveys

The daily echo integration survey results can be compared to the results of echo sounder surveys by the Fishery patrol vessel COMOX POST and the chartered roe maturity test fishing and tagging seiner PACIFIC HARVESTER. In carrying out the echo sounder surveys neither the patrol vessel nor the test fishing vessel used a predetermined track-line grid to ensure complete coverage of the area searched. They ran through what they considered likely areas, and only when fish were encountered did they adopt a search pattern to determine the boundaries of the school or layer. Thus, the search for schools tended to be random; only when large bodies were discovered did the search become more systematic. To convert the area of a school to tonnage the patrol boat used a table relating intensity, at 3 levels, and school depth to tons/mi^2. The seiner either used this system or relied on the past experience of the captain in estimating school or layer size in tons. While the tabular data utilized the best information available to the Department from past

years, it was derived from a variety of sources from uncalibrated sounders of unknown stability. Seiner captains, from their past fishing experience, are very skilled in estimating the size in tons of individual schools, but are not as familiar with converting extensive layers into tonnage. The test fishing vessel estimates form one source from which the Fisheries Officer in charge of the area derives his estimate of the amount of herring on the grounds. The second source is the patrol vessel's estimates.

The results of the echo integration surveys and the echo sounder surveys (Table 7) do not agree well. The echo sounder estimates, except in 2 instances, are much smaller than the echo integration estimates, but not proportionately so. The disagreement seems greater for estimates from the western part of Barkley Sound containing the actual spawning grounds than for Imperial Eagle Channel. In the former region, echo sounder estimates were about one-quarter to one-third (in one instance 1/10) the echo integration estimates, in the latter region they were about one-third to one-half. The differences probably result from incomplete coverage as well as from the use of uncalibrated equipment and problems resulting from the method of converting area into tonnage.

The echo sounder surveys also tended to miss completely some large bodies of herring, especially those that appeared relatively briefly in inshore waters (Table 7, Feb. 19, 22, and Mar. 2). The reason probably is, again, the lack of systematic coverage of the area. The results of these surveys do not reflect the build-up of stocks as clearly as do the echo integration results.

Although the echo sounder results showed the build-up and decline of herring concentrations in Imperial Eagle Channel between March 1 and 7, they did not reflect the changes in biomass near the spawning grounds -- in the Barkley Sound West region. The echo integration surveys showed that the herring concentrations in Barkley Sound West started to build about Feb. 28 (1,477 t), reached 4,983 t on Mar. 2, 7,389 t on Mar. 7, and declined to 4,012 t on Mar. 8 and 1,766 t on Mar. 9. The build-up was missed because of equipment failure for perhaps the 3 most critical days, Mar. 3-5. The echo sounder surveys reported 726-907 t on Mar. 1, and then 1,360 t unchangingly from Mar. 3 to Mar. 8. These surveys were made primarily by the patrol vessel. In Imperial Eagle Channel, on the other hand, the echo sounder surveys results, although low in comparison to the echo integration results, showed a build-up from 362-454 t on Mar. 1 to 3,628-4,535 t on Mar. 4 and 5, then a decline to 2,721-3,175 t on Mar. 6, and to 1,361-1,633 t on Mar. 7, and 136 t on Mar. 8.

The low and unchanging estimates in Barkley Sound West in the days immediately prior to and during spawning are a major reason why the fishery officers' estimate of the total herring spawning stock in Barkley Sound (about 5,440 t) was so much lower than either the estimate derived from the diver's spawn survey (11,650 t) or the echo integration estimate of 12,000-14,000 t. Why the fishery officers' estimate should remain unchanged in the period immediately prior to and during spawning is not clear. They would be expected to vary and indeed the Imperial Eagle Channel estimates showed they must have.

The reliability of the echosounder surveys would be increased if these surveys followed a regular predetermined grid of track-lines at regular

time intervals. This approach should reduce the chances of missing large concentrations, and should allow the build-up of stocks and particularly the movement of fish ready to spawn to be followed from one part of the Sound to another. Since 2 vessels are usually available, the patrol vessel and the test fishery vessel, the 2 major areas, Barkley Sound West and Imperial Eagle Channel, could be monitored simultaneously. This would make the problem of interpreting movement between areas more tractable and should lead to more reliable estimates of the total size of the spawning stock.

The use of standardized, electronically stable, calibrated equipment in all patrol vessels not only on the actual surveys but also in the production of the tabular data for conversion of area to tonnage should also improve estimates.

The use of standardized echo sounders on chartered test fishing vessels would be impractical. However, each skipper-equipment combination could be checked or "calibrated" over the array of standard targets. Each skipper could compare the intensity level of the resulting echograms with the known "equivalent tons of herring" from these targets. A standardizing factor could be obtained for each skipper-equipment combination to adjust as necessary the results of his actual surveys.

CONCLUSIONS

1. The February-March, 1982, hydroacoustic survey of Barkley Sound showed that surveys on inshore grounds were feasible and could be used to determine the distribution and amount of herring on the spawning grounds.

2. Herring spawn mainly in the northwest part of Barkley Sound. In 1982, they apparently approached from offshore along two paths -- directly through Felice Channel and to a lesser extent through Loudoun Channel, and from Imperial Eagle Channel. In the early part of the season, herring were not present in inshore waters near the spawning grounds for protracted periods. Bodies of herring, sometimes large (11,059 t on Feb. 22), would move in and apparently out again in a matter of a day or two. Build-up for the first spawning wave (March 7-10) did not begin until about March 2, when 4,983 t were located in Newcombe Channel. By March 7, the estimate was 7,389 t. No large concentrations were found in Imperial Eagle Channel until March 4 or 5; the next day there were estimated to be 6,919 t there. After spawning started, the quantity of herring declined rapidly. By March 8, there were only 2,261 t in Imperial Eagle Channel, and by March 9, 1,089 t there and 1,766 t in Newcombe Channel.

3. The hydroacoustic surveys yielded daily estimates of the amount of herring near the spawning grounds, and provided certain assumptions were made about movement, an estimate of the total size of the spawning stock (to March 10).

4. The hydroacoustic estimate of the amount of herring contributing to the first wave of spawning varied from 10,261 t to 14,308 t depending on the assumptions made. Using the most reasonable assumptions, the best estimate is probably between 12,000 and 14,000 t. This estimate agrees well with the divers' spawn deposition estimate of 11,650 t in the first wave, especially when it is considered that the latter method measures fish that actually spawned, while the former measures fish on the grounds. This hydroacoustic estimate will thus include a proportion of fish that may not spawn until the later, second wave, or may move to another area. The tag recovery program did indicate that before the first spawning, some second wave spawners were on the grounds and some herring did move to other areas. However, no estimate was possible of these components in relation to the major component, the first wave spawners. While the limits of error of both methods are difficult to assess, the agreement achieved suggests either that the errors associated with two totally independent methods were of the same size and in the same direction, or more probably that both methods produce useful estimates of absolute biomass.

5. Estimates from individual daily surveys were compared to estimates made by the fishery patrol vessel and the test fishery vessel. The agreement was not good. The fishery officers' estimates, except on one or two occasions, when stocks were small, were much smaller than the echo integration estimates. They apparently missed completely some large bodies of herring, especially those that appeared relatively briefly in inshore waters early in the season. Only in Imperial Eagle Channel did their estimates reflect the build-up and decline of the stock prior to and after spawning. In Barkley Sound West, where the main spawning grounds lie, the echo integration estimates showed a pronounced steady build-up in stock prior to spawning and an abrupt decline as the first wave of spawning occurred. The echo sounder estimates showed little evidence of change, but retained the same value over the 5-day period during which the echo integration estimate and the echo sounder estimate in Imperial Eagle Channel first increased and then declined. The echo sounder estimate of total stock size in Barkley Sound West was 1,360 t compared to a maximum echo integration estimate for the area of 7,389 t, and in Imperial Eagle Channel was 4,082 t compared to the maximum echo integration estimate of 6,919 t. Adding produces a total for the fishery officer survey of 5,442 t and for the echo integration survey of 14,208 t.

6. The results of the fishery officers' survey would probably be much improved if these surveys had followed a regular predetermined grid of track-lines at regular time intervals, had used standardized calibrated equipment of proven stability, and had improved factors for converting school area into tonnage.

7. In inshore spawning ground surveys of herring, the error and bias previously associated with hydroacoustic estimates appear to be reduced. Three probable sources of bias previously recognized are reduced to the point where they may not be of major importance. These sources are the determination of species composition, which in spawning ground surveys presents little or no problems, the definition of stock boundaries, which can readily be defined through the extension or addition of track-lines as necessary, and the "visibility" of herring to the sounder with no evidence of obvious avoidance behavior. Of the remaining sources recognized, the errors in estimating target strength appear less than the original subjective

estimate, since Edwards' (1980) experimentally determined in situ value agrees with our calculated value. Calibration is at the "state-of-the-art" level and has now been repeated sufficiently often to show that the system has remained stable. The errors associated with the hydroacoustic estimates will then be related primarily to the estimation of variance. While existing methods for estimating variance do not appear properly applicable to the technique, they may indicate the probable level to be encountered, even though they do not provide a satisfactory estimate. The probable level of the relative variance indicated was between 12 and 48%, and was dependent primarily on the range of density values. When the range is large, over 100 times, high values of relative variance result; when the range is small, less than 10 times, the relative variance is small.

8. The hydroacoustic surveys employed a predetermined grid of track-lines. Flexibility was maintained, as additional track-lines could be added, usually between existing lines, to define better the boundaries of large concentrations; or subtracted in areas where no herring were present. Some modification may be required to improve the definition of concentration boundaries when the fish are in very shallow water at spawning time. In such circumstances it may be better to abandon fixed 9-kn track-lines in favor of a slow speed zig-zag or random search to determine inshore boundaries in limited areas.

10. Surveys were conducted over the track-lines by night and by day. The results of the nighttime surveys when herring were present as a widespread layer were preferred to those of the daytime when herring occurred in dense but often widely separated schools. The nighttime estimates were generally larger than the daytime estimates, especially when herring were abundant, and seemed to provide a more cohesive and readily interpretable picture of the changes in biomass and distribution. In future surveys of this type, at least in areas where there is widespread layering of herring at night, daytime surveys could be discontinued. The daylight hours could then be allotted to preliminary surveys to determine where definitive night surveys should be made.

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The conduct of a survey or an investigation is a team effort from planning through to reporting. Some people contribute throughout, others at one stage or another. In bringing this survey to a successful conclusion, I would like to acknowledge particularly the cooperation and assistance of Dr. Robert Kieser. He was responsible not only for much of the conception of the echo integration system that has emerged from the basic units, but by necessity in these times of restraint also has provided the technical expertise when malfunctions have occurred in the field. Dr. Kieser and Dr. T. Mulligan also participated in the operational side of the survey for a week thereby enabling others to obtain a welcome break. L. W. Barner and W. Ryan assisted with the installation of the equipment on the chartered

seiner EASTWARD HO, and with its operation. The former assisted with the processing of the data, and with the operation of the vessel; the latter was responsible for the shipboard computer operation and data handling.

A survey cannot be successful without the whole-hearted cooperation of the captain and crew of the survey vessel. The running of accurately positioned track-lines at 9 kn at night as well as by day in an area like Barkley Sound requires a first rate knowledge of the area and confidence in his own ability and in his vessel and crew. The seiner trawler EASTWARD HO, Capt. G. Sigmund and his crew proved more than equal to this task.

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Table 1. Schedule of operations, Barkley Sound Hydroacoustic Survey, February 18 to March 12, 1982.

Date	Day or night	Transducer towed (T) or side-mounted (S)	Integration file no.	Time Start	Time Finish	Region Surveyed and Remarks	Track-lines Run
Feb 18	D	T	A01-03	0851	1423	Outer Imperial Eagle	A11, B10A, A09
						Inner Imperial Eagle	C3-C13 (C5 EF)
	N	S	N01	1843	2306	Peacock Ch.	B11A-E9A
						Sechart Ch.	E7-4
						Pinkerton Is./ David Ch.	E3-1,E51-53
						David Ch.	E54-65
						Toquart Bay	E66-71
						Stopper Is.	E72, GI1&2, E55-56
Feb 19	D	S	A04-06	0741	1310	Peacock Ch.	E11A-9
						Sechart Ch.	E7-4
						Pinkerton Is./ David Ch.	E3-1, E51-53
						David Ch.	E54-65
						Toquart Bay	E66-71
						Stopper Is.	E72
						Macoah Pass.	E73
						Newcombe Ch.	E26,D14-14A
	D/N			1300	?	Ucluelet. Picked up F. Taylor. Lengthened and tested side mount, transducer, unsatisfactory	
Feb 20	D	T	A07,08	0806	1605	Outer Imperial Eagle	A11-1,A13,A13A
	N	T	N02	1935	0159	Outer Imperial Eagle	A15-13,A13A,A11-1
Feb 21	D	T	A09	0731	1253	Trevor Ch.	R1-2,F1-11,R3-15
	N	T	N03	1821	2043	Trevor Ch.	R1-2,F1-11,A3-11
Feb 22	D	T	A10	0739	1323	Brabant Is.	E14-17
						Forbes Is.	E18-22
						Newcombe Ch.	E23-27, D14-15
						Felice Ch.	D16-26
	N	T	N04	1833	2310	Brabant Is.	E14-17
						Forbes Is.	E18-22
						Newcombe Ch.	E23-26,D14-15
						Felice Ch.	D18-26

Table 1. (cont'd)

Date	Day or night	Transducer towed (T) or side-mounted (S)	Integration file no.	Time Start	Time Finish	Region Surveyed and Remarks	Track-lines Run
Feb 23	D	-	-	0800	-	Ucluelet. Shorten transducer side mount	
	N	T	N05	1834	2329	Loudoun Ch.	D5-4
						Outside Broken Gr.	D3-1,B14-12
						Outside Imperial Eagle	B11-1
Feb 24	D	S	A11	0935	1201	Newcombe Ch.	D14A-14,E27-23
				1300	1700	Ucluelet - crew change	
	N	S/T	N06,07	1745	2352	Brabant Is.	E13-12
						Peacock Ch.	E10A-L
						Sechart Ch.	E7-E4
						Pinkerton Is./ David Ch.	E3-1, E51-53
						David Ch.	E54-65
						Toquart Bay	E66-71
Feb 25	D					Repair transducer	
	N					To Alberni to pick up Dr. Abby Swartz.	
Feb 26	D	S	A12;B12	0759	1407	Brabant Is.	E13-11A
						Peacock Ch.	E10A-L
						Sechart Ch.	E7-4
						Pinkerton Is./ David Ch.	E3-1,E51-53
						David Ch.	E54-65
						Toquart Bay.	E66-71
						Stopper Is.	E70-72,GI1-4
						Forbes Is./ Brabant Is.	E21-15
	N	S	N08,09	1840	0200	Forbes Is.	E20-18
						Brabant Is.	E17-11A
						Peacock Ch.	E10A-L
						Sechart Ch.	E7-4
						Pinkerton Is./ David Ch.	E3-E1,E51-53
						David Ch.	E54-65
						Toquart Bay	E66-71
						Stopper Is.	E72,G2 1&2

Table 1. (cont'd)

Date	Day or night	Transducer towed (T) or side-mounted (S)	Integration file no.	Time Start	Time Finish	Region Surveyed and Remarks	Track-lines Run
Feb 27	D	S	A13	1128	1503	Forbes Is.	E16-18
						Newcombe Ch.	E20-27,W1-2
						Macoah Pass.	E73
	N	S	N10	1847	2322	Forbes Is.	E16-18
						Newcombe Ch.	E19-28
						Macoah Pass.	E73
Feb 28	D	S	A14-16	1039	1549	Newcombe Ch.	E26,D14-15
						Felice Ch.	D16-26
						Loudoun Ch.	D6-5B,E14
	N	S	N11	1844	2338	Newcombe Ch.	E26,D14-15
						Felice Ch.	D16-26
						Loudoun Ch.	D7-5A,E14
Mar 1	D					Skiff on beach; echosounder problems	
	N					Echosounder problems	
Mar 2	D	S	A17	0852	1436	Brabant Is.	E14-17
						Forbes Is.	E18-22
						Newcombe Ch.	E23-28,D14-15
						Felice Ch.	D18,18A-B
						Newcombe Ch.	Z1&2,W1-3
						Forbes Is.	E22
						Stopper Is.	G14-12
						David Ch./ Pinkerton Is.	E55-51,E1-2
	N	S	N12	2006	2343	Newcombe Ch.	D1A,E27-22
						Forbes Is.	E21-18
						Brabant Is.	E17-14
						David Ch./Is. Pinkerton Is.	E1-2,E51
						Echosounder lost power	
Mar 3	D					Echosounder problems awaiting alnico transducers from Nanaimo	
	N						

Table 1. (cont'd)

Date	Day or night	Transducer towed (T) or side-mounted (S)	Integration file no.	Time Start	Time Finish	Region Surveyed and Remarks	Track-lines Run
Mar 4	D					Installed alnico transducer. Tested alnico transducer; failed source of problems shown to be in echosounder.	
Mar 5	D					Dr. Kieser arrived from Nanaimo repaired sounder.	
	N						
Mar 6	D	S	A18,19	0748	1330	Outer Imperial Eagle	A13.7-13.1, A13A1-A6 A11-3
	N	S	N14	1912	0015	Outer Imperial Eagle	A13.6-B1,A13 A1-5 Z1-5,A11-3
Mar 7	D	S	A20-22	0744	1510	Outside Imperial Eagle	B1-13
						Outside Broken Gr.	B13-41,D1-2
						Loudoun Ch.	D3-7C
	N	S	N15	1721	0112	Felice Ch.	D26-16
						Macoah Pass.	E73
						Newcombe Ch.	W3-1,E28-22
						Forbes Is.	E21-18
						Brabant Is.	E17-14A,E13-11A
						Loudoun Ch.	D5-7A-C
						Peacock Ch.	E10A-D
						Pinkerton Is./ David Ch.	E1-3,E51-53
						David Ch.	E54-63
Mar 8	D	S	A23-24	0739	1445	David Ch.	E63-54
						Pinkerton Is./ David Ch.	E53-57,E1-3
						Peacock Ch.	E10D-A
						Brabant Is.	E11A-17
						Forbes Is.	E18-22
						Newcombe Ch.	E23-28,D14-15
	N	S	N16-17	1828	0101	Felice Ch.	D16,D17-24,D24-20
						Outer Imperial Eagle	A13.6-13.1,A13A1&2 Z1-9, A13-1

Table 1. (cont'd)

Date	Day or night	Transducer towed (T) or side-mounted (S)	Integration file no.	Time Start	Time Finish	Region Surveyed and Remarks	Track-lines Run
Mar 9	D	S	A25	0757	1304	Outer Imperial Eagle	A1-11,Z1-9,ABA1-6 E10D,E3
	N	S	N18.19	2005	2337	Pinkerton Is./ David Ch.	E2-1,E51-53
						David Ch.	E52-65
						Stopper Is.	E55, GI1-4
						Forbes Is.	E22-21
						Newcombe Ch.	E23-28
Mar 10	D N					Searching for fish throughout Sound	
Mar 11	D					Searching for fish throughout Sound	
Mar 12	D	S	A26	0919	1530	Trevor Ch.	H1-3
					1530	Then searching for fish Survey abruptly terminated on instructions from Herring Management Committee	

Table 2. Herring biomass (in metric tons) by region for day surveys of Barkley Sound, February 18 to March 12, 1982.

	Feb 18	Feb 19	Feb 20	Feb 21	Feb 22	Feb 24	Feb 26	Feb 27	Feb 28	Mar 2	Mar 6	Mar 7	Mar 8	Mar 9	Mar 12
Toquart Bay	—	106	—	—	—	—	20	—	—	—	—	—	—	—	—
Stopper Isl.	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—
Macoah Pass.	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—
Forbes Isl.	—	—	—	—	142	—	479	205	—	109	—	—	167	—	—
Newcombe Ch.	—	496	—	—	2009	619	—	25	166	433	—	—	3464	—	—
Felice Ch.	—	—	—	—	1673	—	—	—	372	402	—	479	105	—	—
David Ch.	—	1212	—	—	—	—	3	—	—	6	—	—	178	—	—
Brabant Isl.	—	88	—	—	1	—	40	2	3	13	—	—	26	—	—
Peacock Ch.	—	—	—	—	—	—	—	—	—	—	—	—	69	—	—
Loudoun Ch.	—	—	—	—	8	—	—	—	10	—	—	220	—	—	—
Pinkerton Isl.	—	10	—	—	—	—	—	—	—	+	—	—	3	—	—
Sechart Ch.	—	41	—	—	—	—	21	—	—	—	—	—	—	—	—
Upper Imperial Eagle Ch.	(43)[a]	—	822	—	—	—	—	—	—	—	1285	—	—	1099	—
Outside Imperial Eagle Ch.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Trevor Ch.	—	—	197	—	—	—	—	—	—	—	—	—	—	—	+
	—	—	(1721)[b]	—	—	—	—	—	—	—	—	—	—	—	—
Outside Broken Gr.	—	—	—	—	—	—	—	—	—	—	—	(138)[a]	—	—	—
Inner Imperial Eagle Ch.	39	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	(37)	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	119	1959	822	1918	3833	619	563	232	551	963	1285	837	4012	1099	+

[a]Rockfish

[b]Anchovy 1376; hake 345.

Table 3. Herring biomass (in metric tons) by region for night surveys of Barkley Sound, February 18 to March 12, 1982.

	Feb 18	Feb 20	Feb 21	Feb 22	Feb 23	Feb 24	Feb 26	Feb 27	Feb 28	Mar 2	Mar 6	Mar 7	Mar 8	Mar 9
Toquart Bay	107	--	--	--	--	5	45	--	--	--	--	--	--	--
Stopper Islands	380	--	--	--	--	--	--	--	--	--	--	137	--	--
Macoah Pass.	--	--	--	--	--	--	--	2	--	--	--	948	--	--
Forbes Island	--	--	--	103	--	--	211	168	--	140	--	524	--	318
Newcombe Ch.	--	--	--	10877	--	--	--	106	138	4802	--	3954	--	332
Felice Ch.	--	--	--	28	--	--	--	--	1280	--	--	--	--	--
David Ch.	1401	--	--	--	--	--	32	--	43	--	--	637	--	1116
Brabant Isl.	191	--	--	37	--	179	69	14	16	41	--	308	--	--
Peacock Ch.	--	--	--	--	--	66	--	--	--	--	--	55	--	--
Loudoun Ch.	--	--	--	14	22	--	--	--	--	--	--	826	--	--
					(12)[c]									
Pinkerton Isl.	57	--	--	--		--	--	--	--	--	--	--	--	--
Sechart Ch.	73	--	--	--	--	69	31	--	--	--	--	--	--	--
Upper Imperial Eagle Ch.	--	886	1162[a]	--	--	--	--	--	--	--	6919	--	2281	--
			(147)[b]											
Outside Imperial Eagle Ch.	--	--	--	--	7	--	--	--	--	--	--	--	--	--
Trevor Ch.	--	--		--	--	--	--	--	--	--	--	--	--	--
Outside Broken Gr.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
					(14)[c]									
Total	2209	886	1309	11059	55	319	388	290	1477	4983	6919	7389	2281	1766

[a]Herring and anchovy (70%)

[b]Hake

[c]Rockfish

Table 4. Total herring biomass (in metric tons) at night, and percent in dense, medium, and light herring layers[a] in single concentrations greater than 1000 t and combined concentrations less than 1000 t, Barkley Sound, February 18 - March 12, 1982.

Date	Numbers of Regions	Biomass				Percentage		
		Total	Dense	Medium	Light	Dense	Medium	Light
Feb 18	1	1401	1361	17	23	97	1	2
	5	815	454	310	44	56	38	5
Feb 20	1	866	650	123	113	73	14	13
Feb 21	1	1162	1115	39	8	96	3	1
	4	184	28	85	69	15	46	38
Feb 22	1	10877	10863	6	5	100	+	+
	4	182	28	85	69	15	47	38
Feb 23	2	29	-	-	29	-	-	100
Feb 24	5	319	121	134	64	38	42	20
Feb 26	5	388	96	171	104	25	44	27
Feb 27	4	290	54	213	23	19	73	8
Feb 28	1	1280	1084	136	60	85	11	5
	3	197	127	8	62	64	4	31
Mar 2	1	4802	4741	50	11	99	1	+
	2	181	-	133	48	-	73	27
Mar 6	1	6919	6731	96	92	97	1	1
Mar 7	1	3954	3827	127	-	97	3	-
	7	3435	1789	1551	95	52	45	3
Mar 8	1	2281	1867	273	141	82	12	6
Mar 9	1	1116	415	700	1	37	63	+
	2	650	314	333	3	48	51	+

[a]Dense herring layers, density values $>0.1\ 3 \times 10^{0}$; medium 0.1×10^{-1} to 0.94×10^{-1}; light 0.95×10^{-3} to 0.94×10^{-2}.

Table 5. Tag recoveries from Barkley Sound pre-roe fishery taggings, because of double tagging maximum and minimum recoveries, in parentheses, are given (Haegele et al. 1982).

Area and fishery of recovery	Catch (t)	Date and Location of Tagging													
		Feb 20 Lyall Pt.	Feb 20 Lyall Pt.	Feb 22 Mayne Bay	Feb 23 Chrow Isl.	Feb 27 Sail Rk.	Mar 3 Chrow Isl.	Mar 3 Chrow Isl.	Mar 4 Mid-Imp. Eagle	Mar 4 Meares Bluff	Mar 5 Chrow Isl.	Chrow Isl.	Mar 6 Pinnacle Rk.	Mar 7 Effingham Rk.	Total
Area 23															
Mar 11-12, 14-15 Permit seine	598	1	7	13 (12)	1	1	3 (2)	2 (1)	2	3	3	4	12	9 (7)	61 (55)
Mar 17-18 Roe seine	3385	2	5	14 (13)	-	3 (2)	1	5 (4)	8 (7)	5	8	12	27 (26)	18 (16)	108 (101)
Area 24															
Mar 8-9 Roe seine	700	-	1	3	-	-	-	3	1	3	2	-	- 2	-	15
Mar 8-9 Roe gillnet	885	-	2	5 (4)	-	-	-	4	1	3 (2)	2	1	3 (2)	-	21 (19)
Mar 14-15 Permit seine	110	-	-	-	1	-	1	1	-	-	-	-	- -	-	3
Area 25															
Mar 7-11 Roe gillnet	2100	-	-	1	-	-	-	-	1	1	2 (1)	-	- -	-	5 (4)
Unknown	400	1	2	5	4	-	-	6	3	2	2	6	7	3	41
Total	8178	4	16	38 (35)	6	4 (3)	5 (4)	18 (16)	15 (14)	14 (13)	17 (16)	23	49 (48)	30 (26)	239 (234)

Table 6. Relative variance (SE/M) in dense and medium, and dense, medium, and light segments of concentrations whose biomass exceeds 1000 t, Barkley Sound, February 18 to March 12, 1982.

Concentration Number	Number of Observations and Relative Variance in Dense Density Exponent +0		Dense and Medium Density Exponent +0 and -0		Dense, Medium and Light Density Exponent 0, -1 and -2	
	No. of Observations	Rel. Var.	No. of Observations	Rel. Var.	No. of Observations	Rel. Var.
N01-1	3	--	16	0.1676	--	--
-2	14	0.1748	24	0.2442	--	--
-3	1	--	3	--	--	
Entire concentration	--	--	--	--	90	0.2342
N03-1	11	0.1161	17	0.1753	23	0.2135
N04-1	1	--	7	0.3767	--	--
-2	15	0.4736	16	0.4075	--	--
Entire concentration	--	--	--	--	54	0.5054
N11-1	1	--	2	--	--	--
-2	3	--	10	0.4956	--	--
Entire concentration	--	--	--	--	43	0.4951
N12-1	24	0.1983	36	0.2212	69	0.2445
N-14-1	16	0.4084	27	0.4261	91	0.4453
N-15-1	37	0.1498	134	0.1579	157	0.1603
N16-1	9	0.3426	27	0.3621	105	0.4280
N18-1	--	--	68	0.1959	74	0.1975

Table 7. Estimated herring biomass in metric tons from day and night echointegration surveys and echosounder surveys, Barkley Sound, February 18-March 12, 1982.

	Echointegration surveys			Echosounder surveys				
	Biomass (t)			Biomass (t) By test-fishing vessel		Fishery Officers		
Date	Day	Night	Areas Surveyed	Day	Night	Day	Night	Areas Surveyed
Barkley Sound West								
Feb 18	--							
		2209	PC,SC,PIC,DC,TB,SI[a]	Not on grounds				
19	1959		PC,SC,PIC,DC,TB,SI,MP,NC	363-454		363		NC,MP,TB,MP,DC
		--	--		--		--	--
20	--		IEC	454-907		454-907		DC,TB,FI,NC,PIC,SI
		--	--		--			TB,MP,FI,NC,BI,DC
21	--		TC	91		91		TC,IEC,CC
		--	--		181			TC
22	3833	--	BI,FI,NC,FL	907-1306		907-1306		NC,LC,FI,DC,TB,PC
		11059	BI,FI,NC,FC		--		--	--
23	EF		--	907		907		PC,LC,NC,FI,DC,TB
		29	LC,OBG,OIEC		--			--
24	619		NC, and crew change	Tofino meeting				
		319	BI,PC,SC,PIC,DC,TB					
25	EF			181		181		
			Port Alberni		+			NC,FI,SI,DC,TB,LC,PC,DC
26	563		BI,PC,SC,RC,DC,TB,SI,FI	726		--	--	TB,DC,FI,NC,LC,BI
		388	FI,BI,PC,SC,PIC,DC,TB,SI		--			TB,DC,BI,LC,NC,FI,SeC
27	232		FI,NC,MP	562		907	--	--
		290	FI,NC,MP,		45c			DC,FI,NC,LC
28	551		NC,FC,LC	+		--	--	LC,FI,DC,NC
		1477	NC,FC,LC		--			TB,AI,IEC
Mar 1	Lost						--	--
			Skiff	726-907		726-907		DC,FI,NC
2	963		BI,FI,NC,FC,SI,DC		--		--	--
		4983	NC,FI,BI,DC	181		--		PC,FI,NC
					--		--	IEC

Table 7 (cont'd).

Date	Echointegration surveys: Biomass (t) Day	Night	Areas Surveyed	Echosounder surveys: Biomass (t) By test-fishing vessel Day	Night	Fishery Officers Day	Night	Areas Surveyed
Barkley Sound West (cont'd)								
Mar 3	EF			363		1360CP[b]		MB,FI,NC,MP
					--		--	--
4	EF			—		1360CP		IEC
					--		--	--
5	EF			—		1360CP		IEC
					--		--	--
6	—		IEC	1360 tagging		—		NC,LC,FI,MC,TB
		--	IEC		--		--	--
7	699	—	OIEC,OBG,LC,FC	907		—	—	MP,FI,NC
		7389	MP,NC,FI,BI,LC,PC,DC		--		1360CP	BSW
8	4012		DC,PIC,PC,BI,FI,NC,FC	1360 tagging				
		--	--		--		907-1360CP	BSW
9	—		IEC	907		--	CP[b]	DC
		1766	PIC,DC,SI,FI,NC		--		--	--
Imperial Eagle and Trevor Channels								
Feb 18			BSW					
		—	—					
19	—		BSW	—		—		--
		--	--		--		--	SeC,IEC
20	882		IEC	—		—		--
		886	IEC		--		--	--
21	1573		TC	181			(91)	SeC,IEC,SaP,TC,CL
		1162	TC		907		--	TC
22	—		BSW	—		—		--
		--	--		--		+	SeC,OIEL

Table 7 (cont'd).

	Echointegration surveys			Echosounder surveys				
	Biomass (t)			Biomass (t) By test-fishing vessel		Fishery Officers		
Date	Day	Night	Areas Surveyed	Day	Night	Day	Night	Areas Surveyed
Imperial Eagle and Trevor Channels (cont'd)								
Feb 23	EF			—		—		—
			BSW		--		--	--
24	—		BSW	—		—		--
		--	--		--		--	--
25	EF			23(CP+PH)		—		SeC, IEC, CC
			Port Alberni		--		--	--
26	—		BSW	—		--		--
		--	--		9		--	SeC, IEC
27	—		BSW	—		—		--
		--	--		--		--	--
28	—		BSW	635-726		362-454		SeC, IEC
		--	--		--		--	--
Mar 1	Lost			454-907		—		SeC, IEC, LC
		Skiff			--		1000	as above
2	—		—	+		—		--
		--	--		726-907[c]		--	CC, IEC
3	EF			--		907		IEC
					2721-3625		1814	CC, IEC
4	EF			2721+		1814		IEC
					3628-4535[c]		4082	IEC
5	EF			--	CP+PH	--		BSW
					—		4082	IEC, CC
6	1285		IEC	--				--
		6919	IEC, CC		2721-3175[c]		2721-3175	IEC, CC
7	--		BSW	--	CP+PH	--		BSW
		--	--		1361-1633[c] CP+PH		--	IEC

Table 7 (cont'd).

Date	Echointegration surveys: Biomass (t) Day	Echointegration surveys: Biomass (t) Night	Echointegration surveys: Areas Surveyed	Echosounder surveys: Biomass (t) By test-fishing vessel Day	Echosounder surveys: Biomass (t) By test-fishing vessel Night	Echosounder surveys: Fishery Officers Day	Echosounder surveys: Fishery Officers Night	Echosounder surveys: Areas Surveyed
Imperial Eagle and Trevor Channels (cont'd)								
8	—			—		1361		IEC
		2281	IEC,CC		136		--	IEC, LC
9	1099		IEC,CC	—	PH	—		BSW
		—	BSW		--		--	

[a] Abbreviations: BI-Brabant Islands; BSW-Barkley Sound West; CC-Coaster Channel; DC-David Channel; IEC-Imperial Eagle Channel; FI-Forbes Island; FC-Felice Channel; LC-Loudoun Channel; MP-Macoah Passage; NC-Newcombe Channel; OBG-Outside Broken Group; OIEC-Outside Imperial Eagle Channel; PC-Peacock Channel; PIC-Pinkerton Channel; SI-Stopper Islands; SeC-Sechart Channel; TC-Trevor Channel; EF-Equipment Failure

[b] CP=Fishery patrol vessel COMOX POST
PH=Roe test fishing and tagging seiner PACIFIC HARVESTER

[c] Surveys made before dawn shown as part of previous night.

Table 7 (cont'd).

Date	Echointegration surveys: Biomass (t) Day	Night	Areas Surveyed	Echosounder surveys: Biomass (t) By test-fishing vessel Day	Night	Fishery Officers Day	Night	Areas Surveyed
Imperial Eagle and Trevor Channels (cont'd)								
Feb 23	EF			—		—		—
			BSW		--		--	--
24	—		BSW	—		—		--
		--	--		--		--	--
25	EF			23(CP+PH)		—		SeC, IEC, CC
			Port Alberni		--		--	--
26	—		BSW	—		--		--
		--	--		9		--	SeC, IEC
27	—		BSW	—		—		--
		--	--		--		--	--
28	—		BSW	635-726		362-454		SeC, IEC
		--	--		--		--	--
Mar 1	Lost			454-907		—		SeC, IEC, LC
	Skiff				--		1000	as above
2	—		—	+		—		--
		—	--		726-907[c]		--	CC, IEC
3	EF			--		907		IEC
					2721-3625		1814	CC, IEC
4	EF			2721+		1814		IEC
					3628-4535[c]		4082	IEC
5	EF			--	CP+PH	--		BSW
					—		4082	IEC, CC
6	1285		IEC	--				--
		6919	IEC, CC		2721-3175[c]		2721-3175	IEC, CC
7	—		BSW	--	CP+PH	--		BSW
		--	--		1361-1633[c] CP+PH		--	IEC

Table 7 (cont'd).

Date	Echointegration surveys: Biomass (t) Day	Echointegration surveys: Biomass (t) Night	Echointegration surveys: Areas Surveyed	Echosounder surveys: Biomass (t) By test-fishing vessel Day	Echosounder surveys: Biomass (t) By test-fishing vessel Night	Echosounder surveys: Fishery Officers Day	Echosounder surveys: Fishery Officers Night	Echosounder surveys: Areas Surveyed
Imperial Eagle and Trevor Channels (cont'd)								
8	—			—		1361		IEC
		2281	IEC,CC		136		--	IEC,LC
9	1099		IEC,CC	—	PH	—		BSW
		--	BSW		--		--	

[a] Abbreviations: BI-Brabant Islands; BSW-Barkley Sound West; CC-Coaster Channel; DC-David Channel; IEC-Imperial Eagle Channel; FI-Forbes Island; FC-Felice Channel; LC-Loudoun Channel; MP-Macoah Passage; NC-Newcombe Channel; OBG-Outside Broken Group; OIEC-Outside Imperial Eagle Channel; PC-Peacock Channel; PIC-Pinkerton Channel; SI-Stopper Islands; SoC-Sechart Channel; TC-Trevor Channel; EF-Equipment Failure

[b] CP=Fishery patrol vessel COMOX POST
PH=Roe test fishing and tagging seiner PACIFIC HARVESTER

[c] Surveys made before dawn shown as part of previous night.

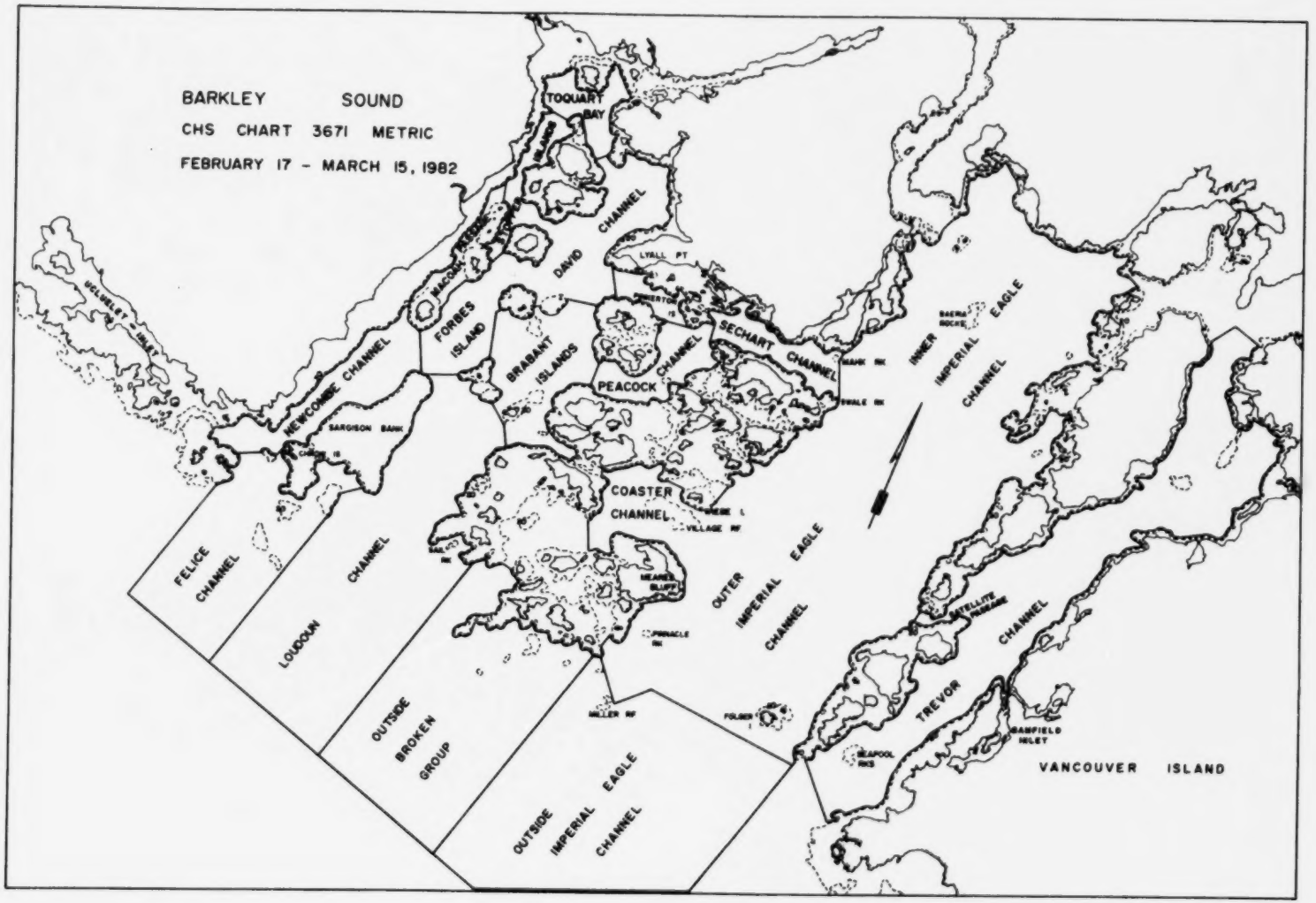


Fig. 1. Hydroacoustic areas in Barkley Sound, February 18-March 12, 1982.

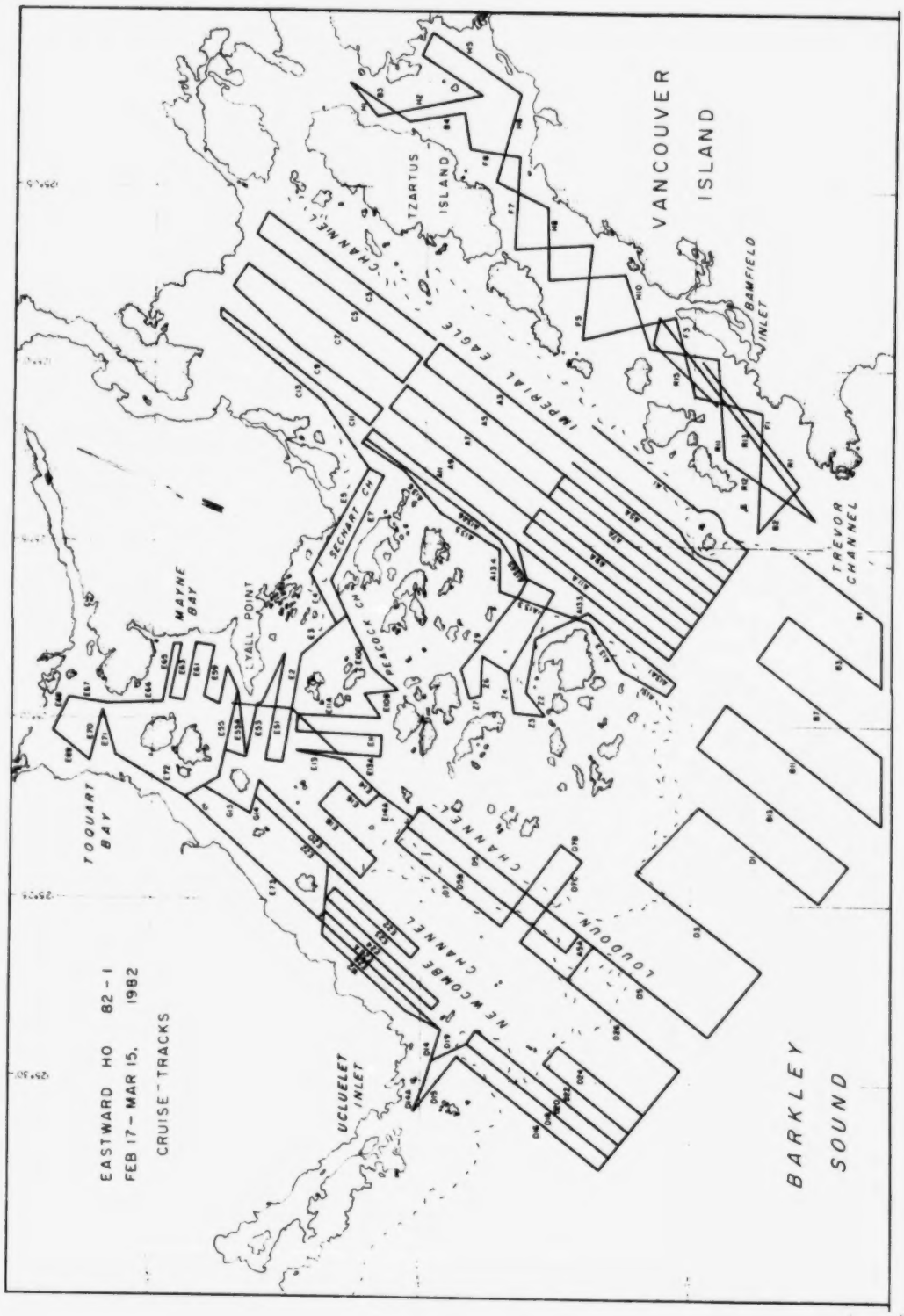


Fig. 2. Hydroacoustic track-lines, Barkley Sound, February 18-March 12, 1982.

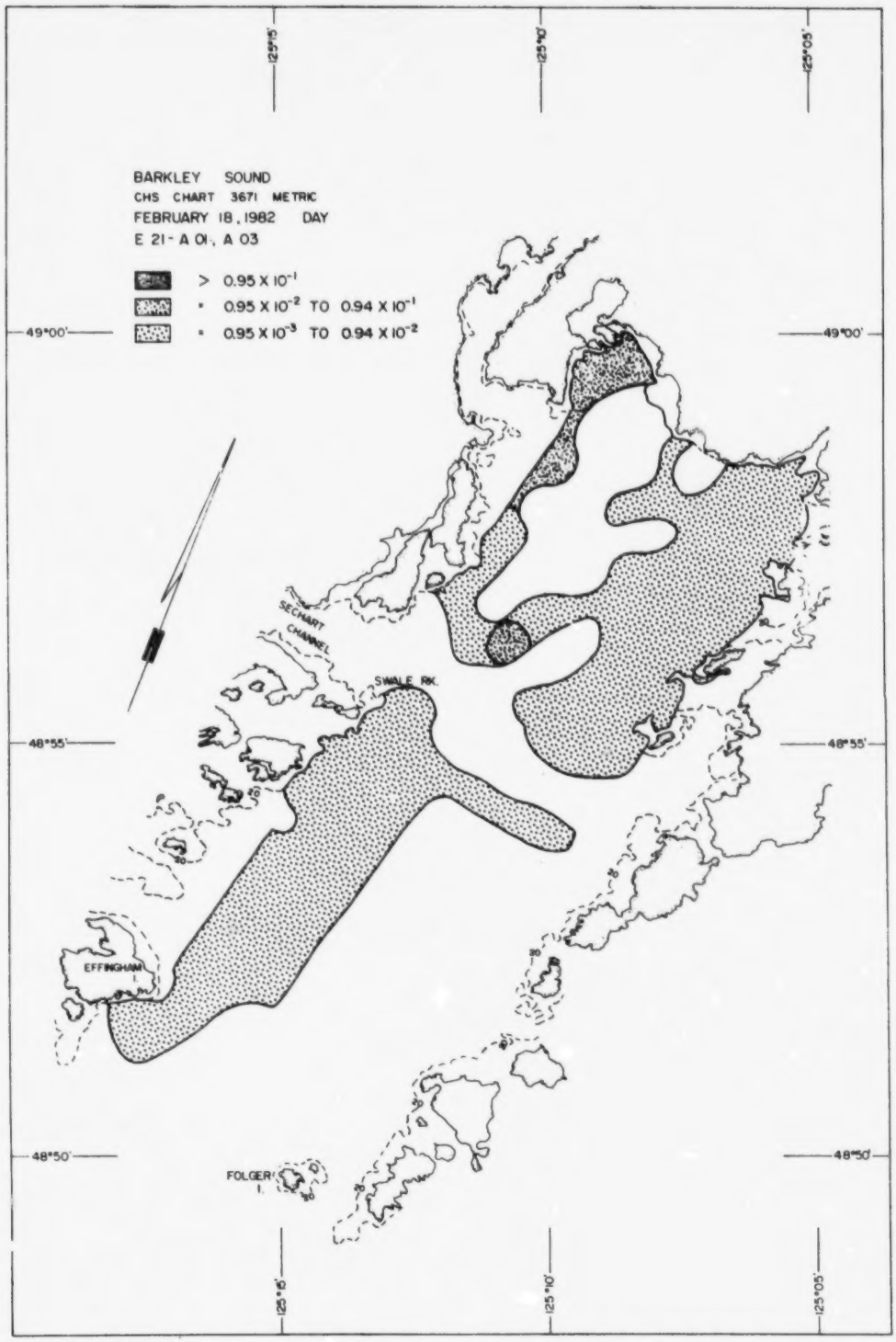


Fig. 3. Distribution of herring biomass by day, Barkley Sound, February 18, 1982.

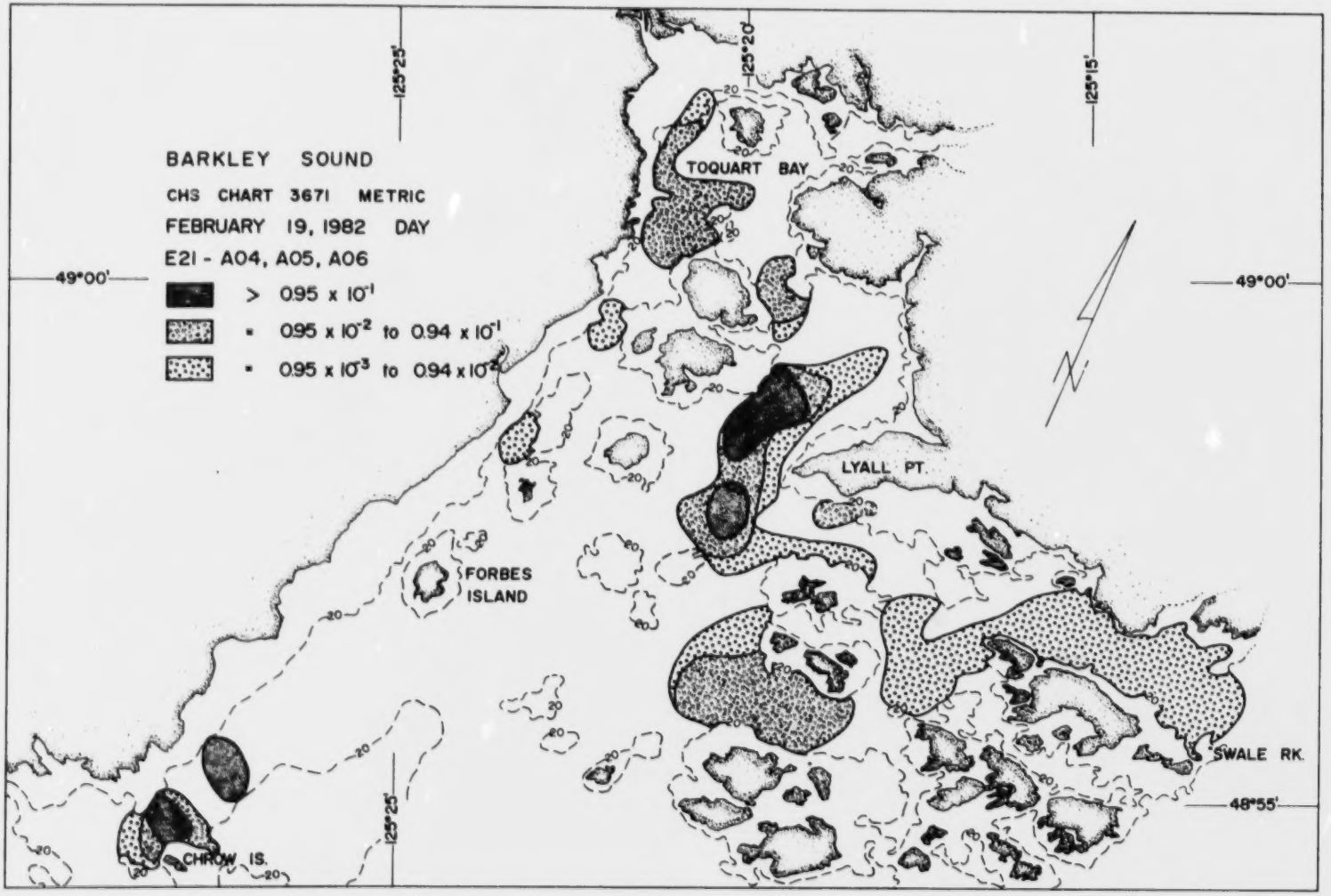


Fig. 4. Distribution of herring biomass by day, Barkley Sound, February 19, 1982.

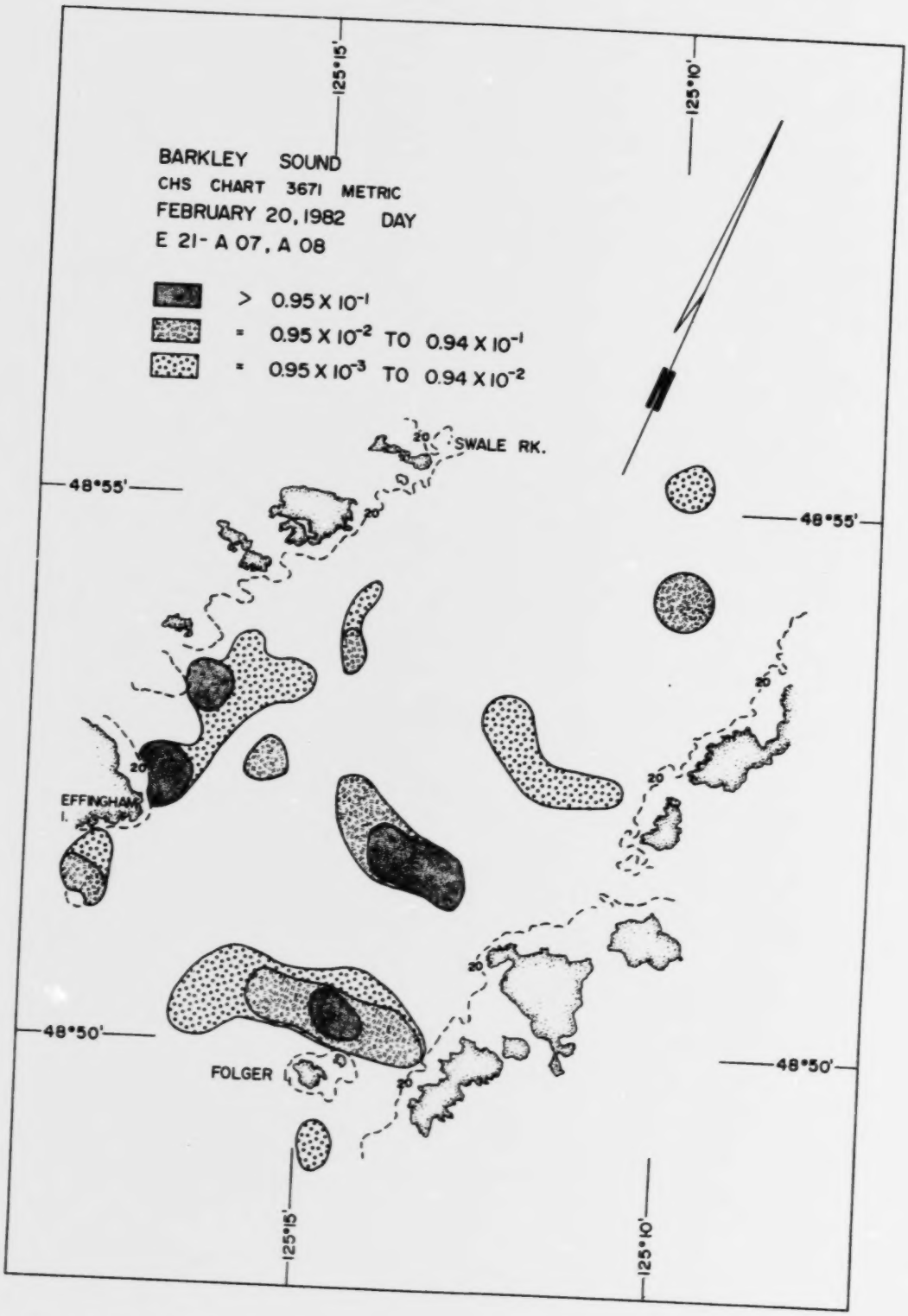


Fig. 5. Distribution of herring biomass by day, Barkley Sound, February 20, 1982.

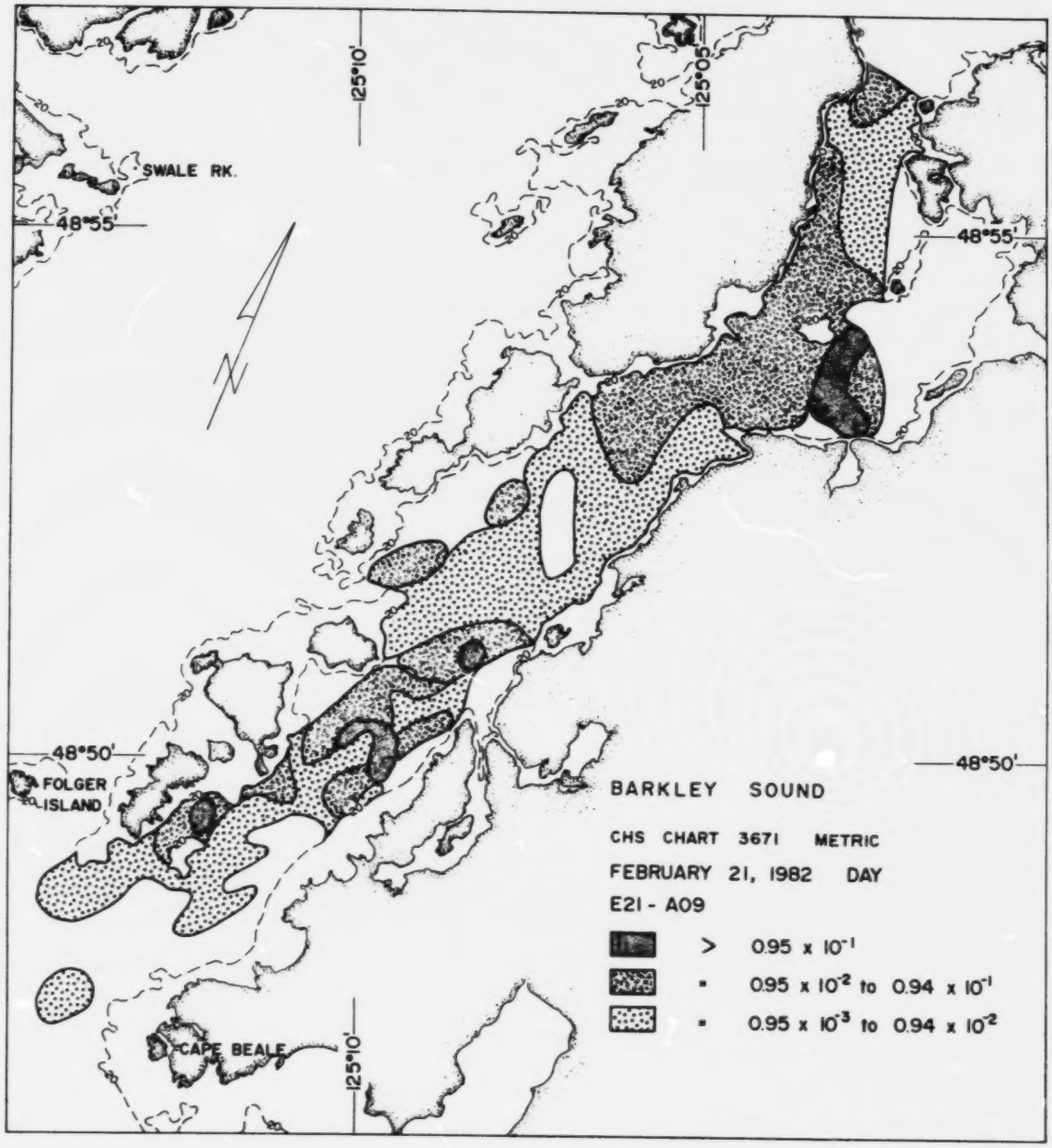


Fig. 6. Distribution of herring biomass by day, Barkley Sound, February 21, 1982.

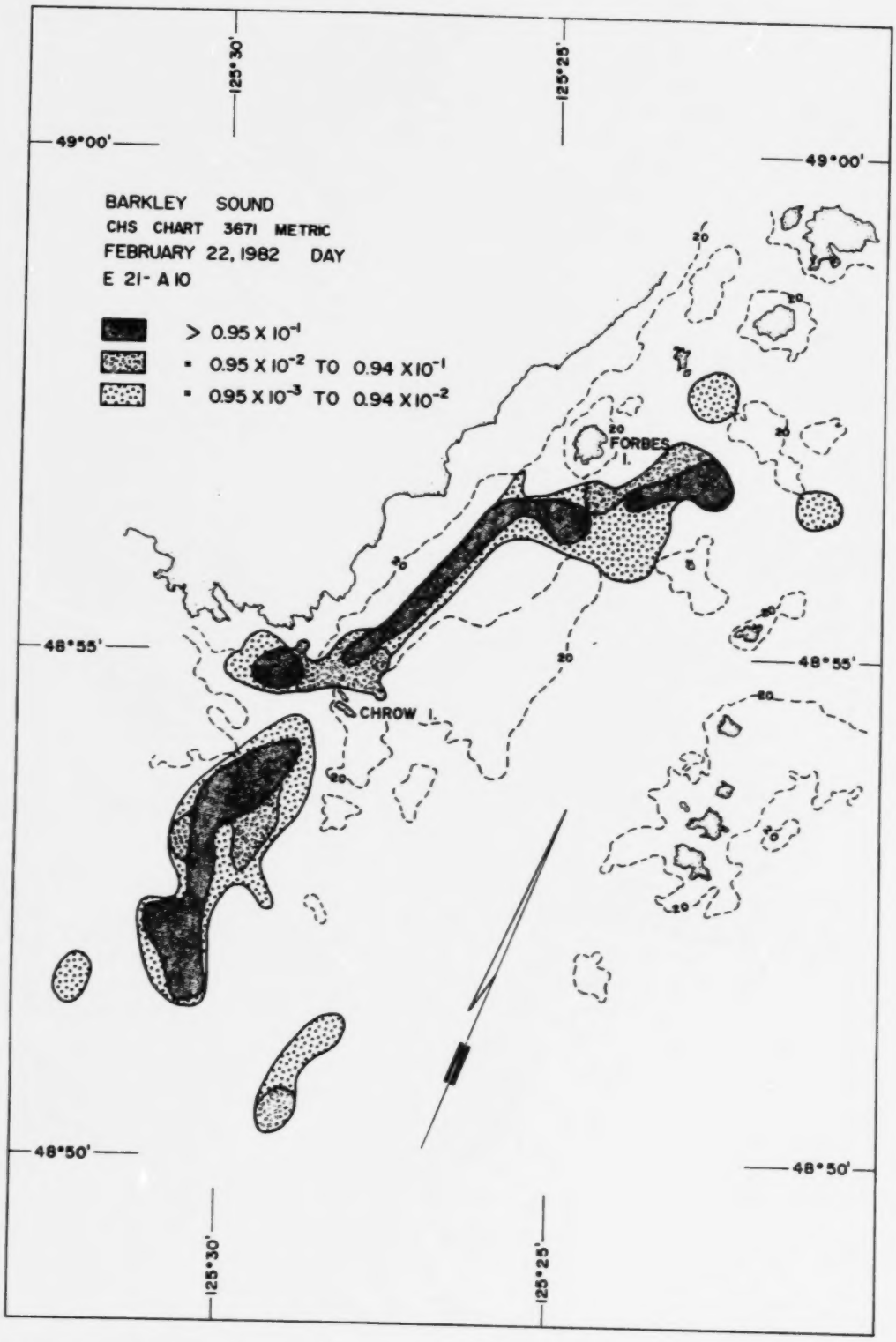


Fig. 7. Distribution of herring biomass by day, Barkley Sound, February 22, 1982.

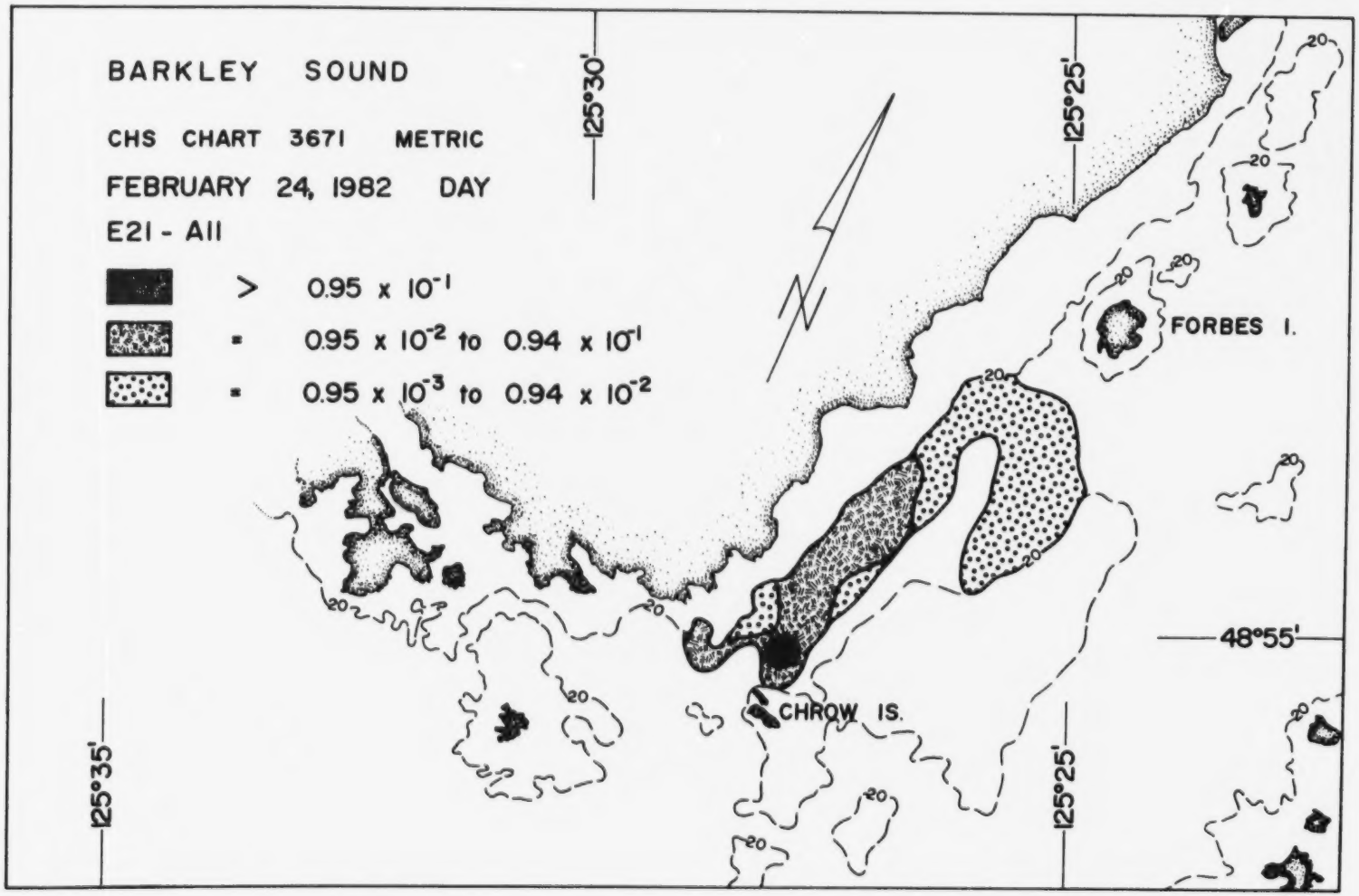


Fig. 8. Distribution of herring biomass by day, Barkley Sound, February 24, 1982.

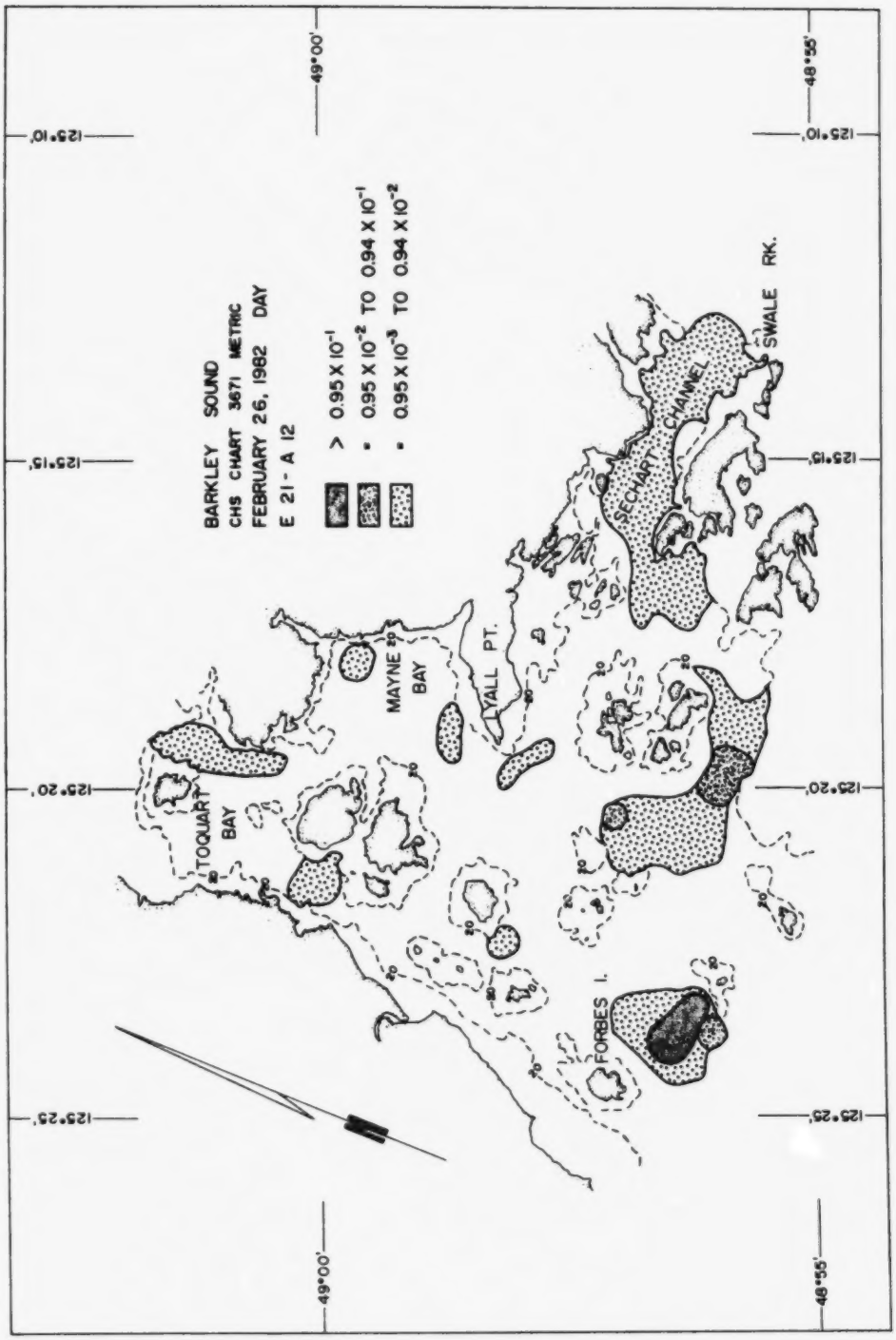


Fig. 9. Distribution of herring biomass by day, Barkley Sound, February 26, 1982.

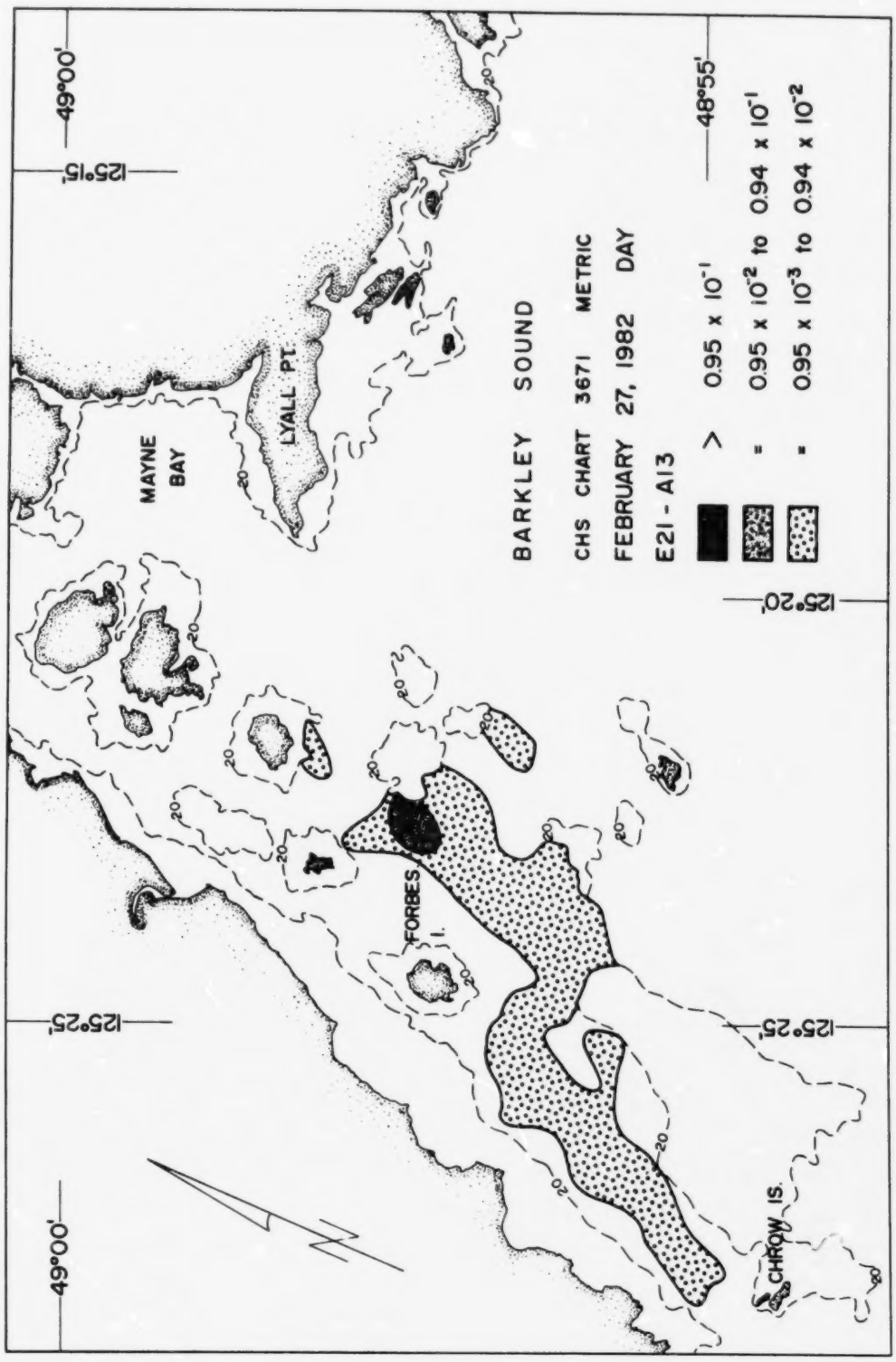


Fig. 10. Distribution of herring biomass by day, Barkley Sound, February 27, 1982.

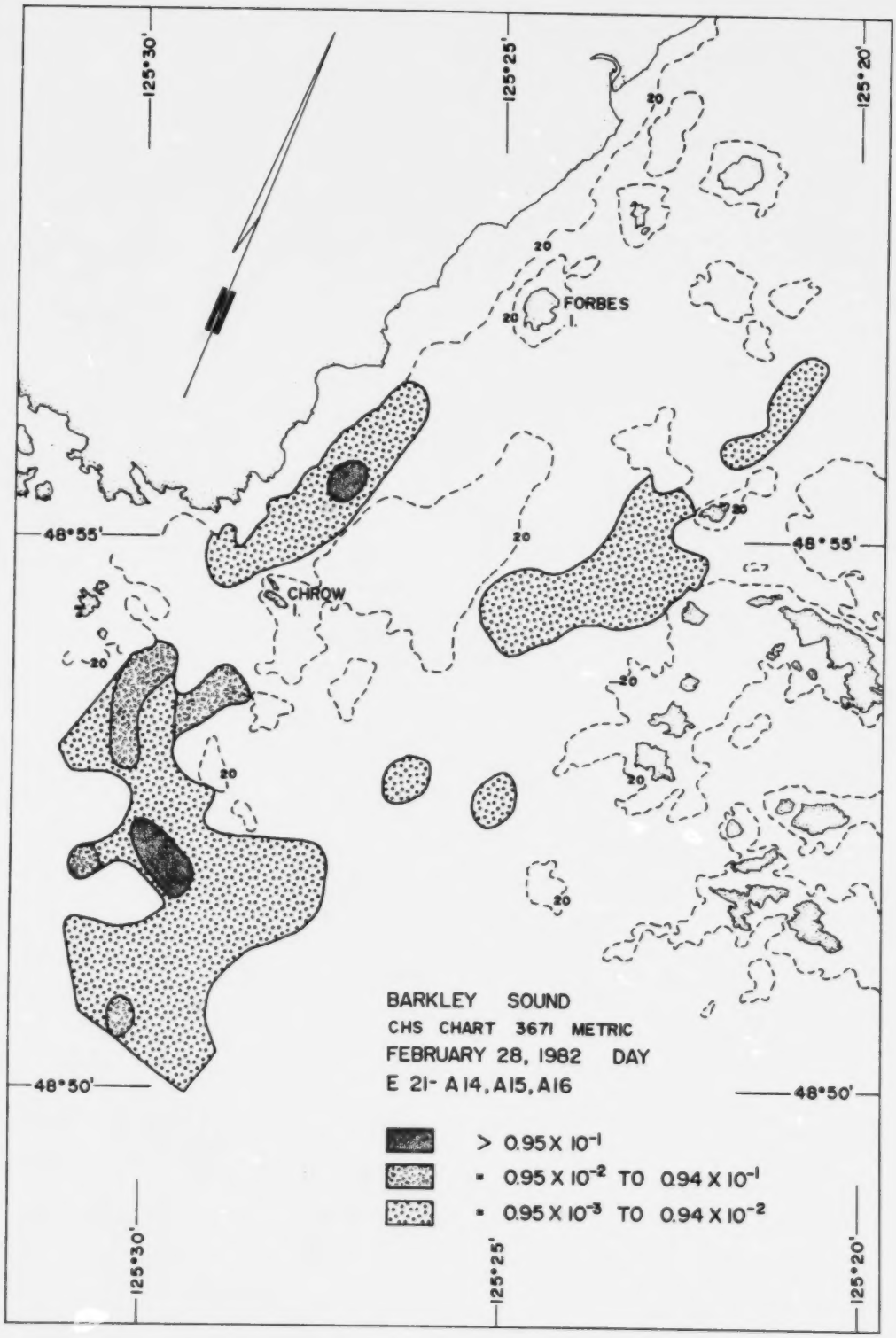


Fig. 11. Distribution of herring biomass by day, Barkley Sound, February 28, 1982.

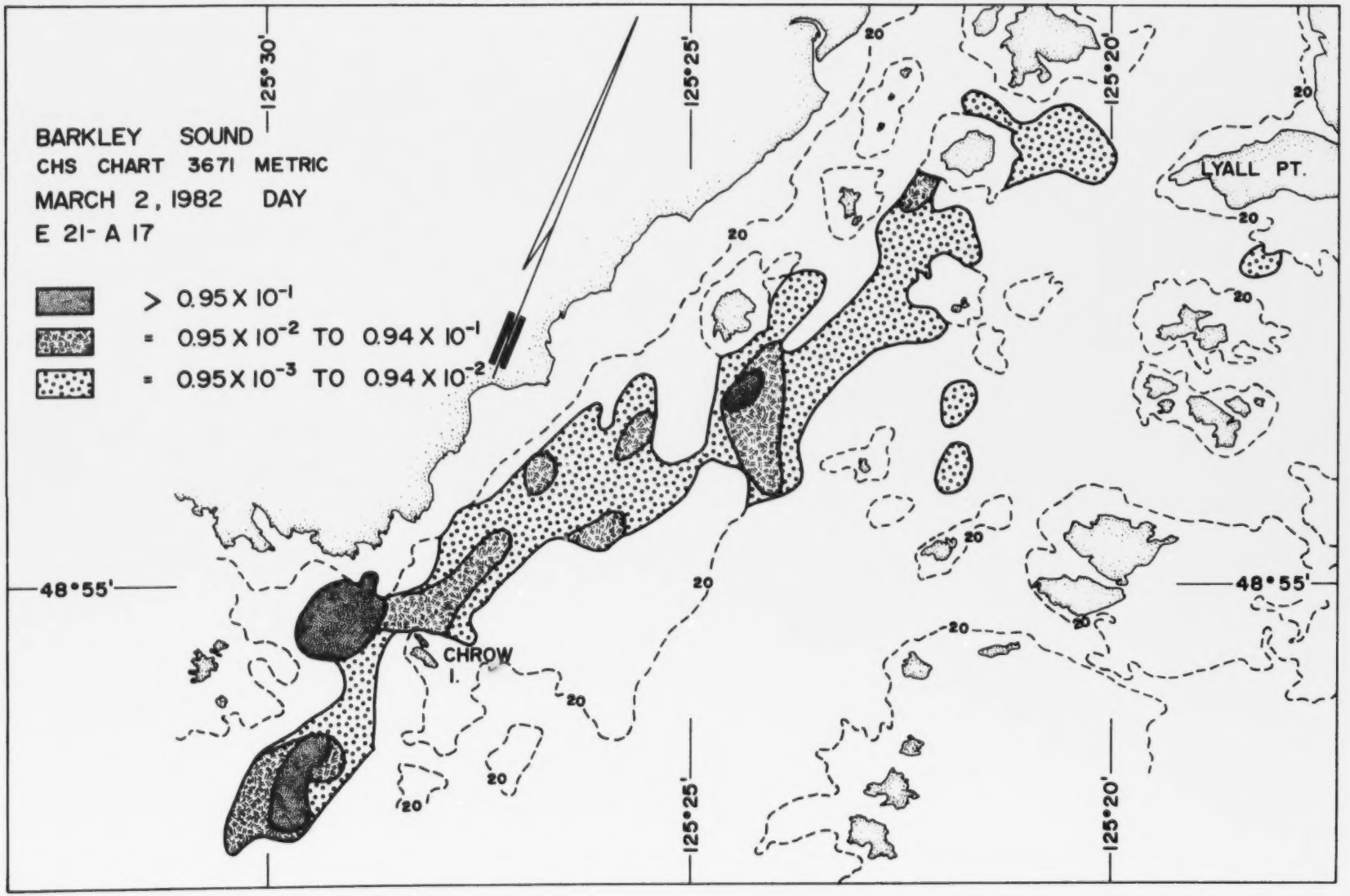


Fig. 12. Distribution of herring biomass by day, Barkley Sound, March 2, 1982.

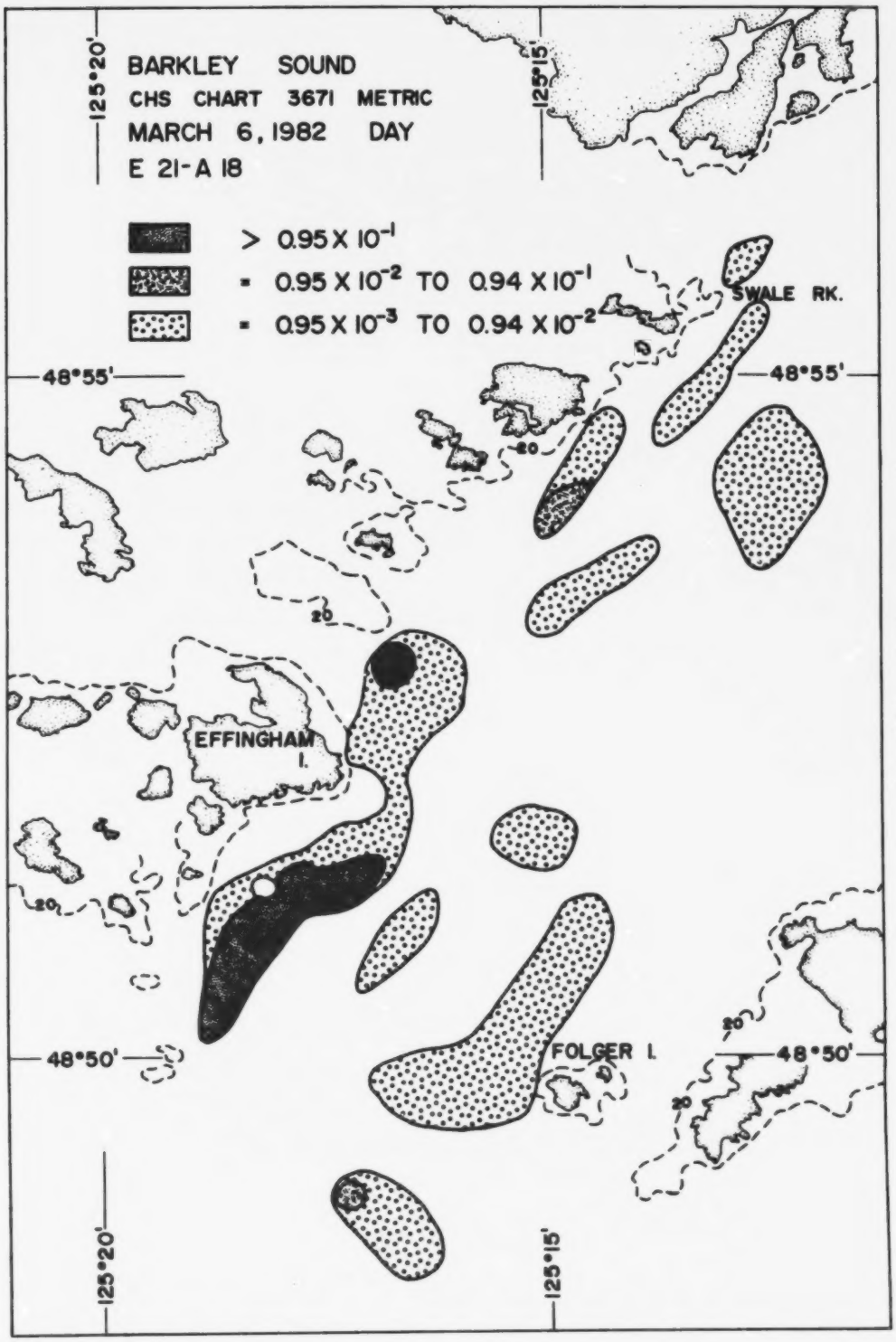


Fig. 13. Distribution of herring biomass by day, Barkley Sound, March 6, 1982.

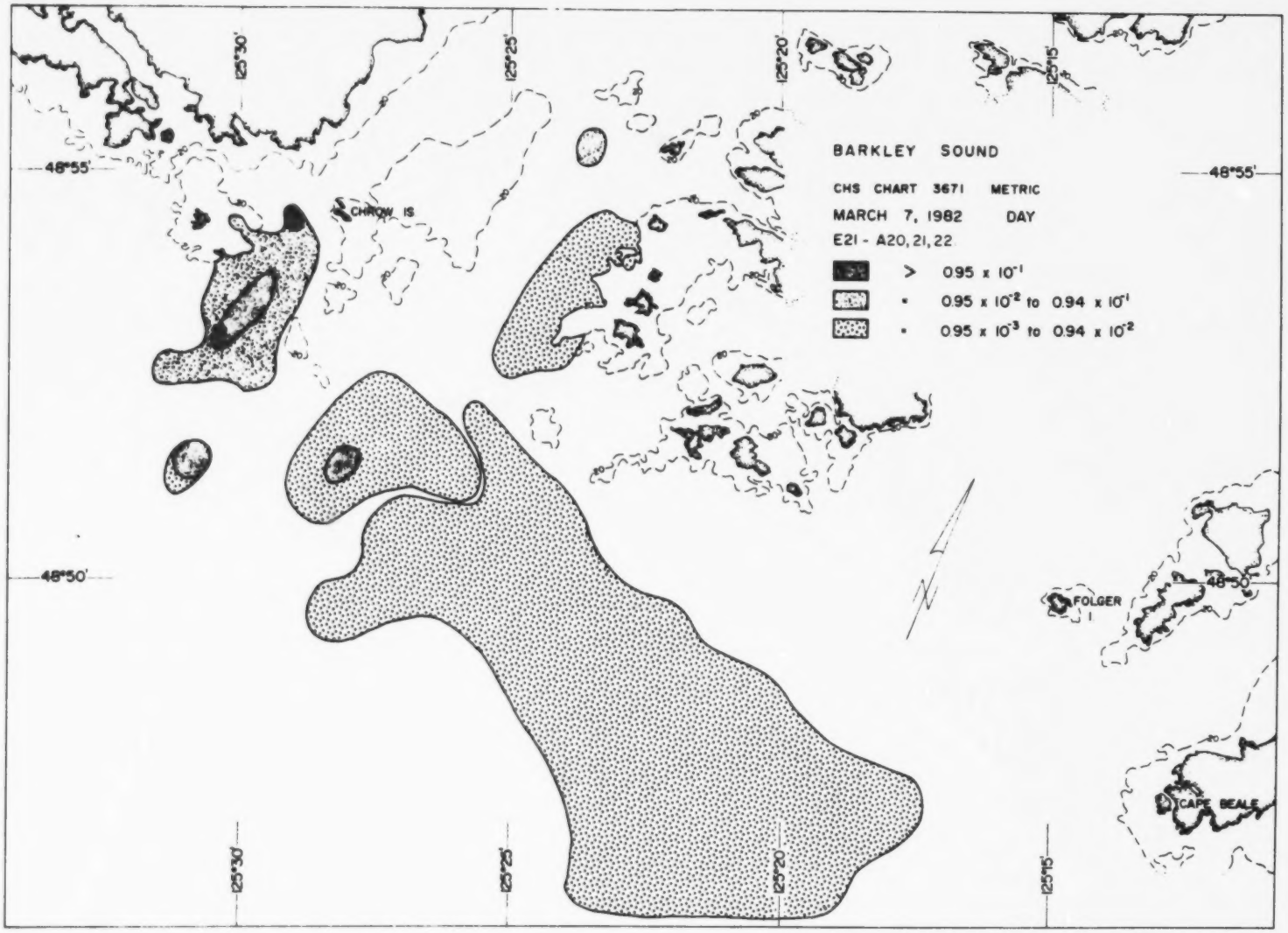


Fig. 14. Distribution of herring biomass by day, Barkley Sound, March 7, 1982.

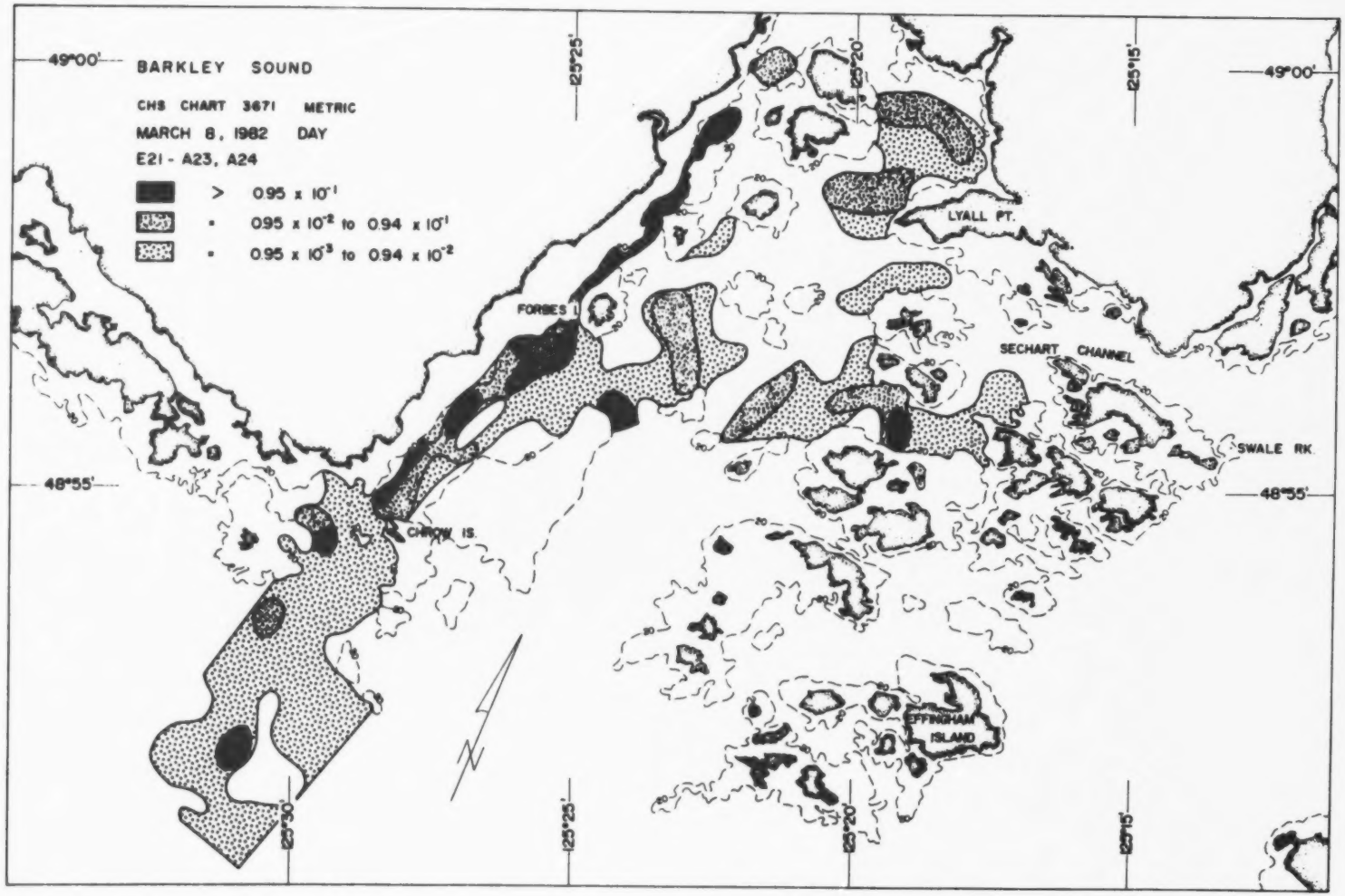


Fig. 15. Distribution of herring biomass by day, Barkley Sound, March 8, 1982.

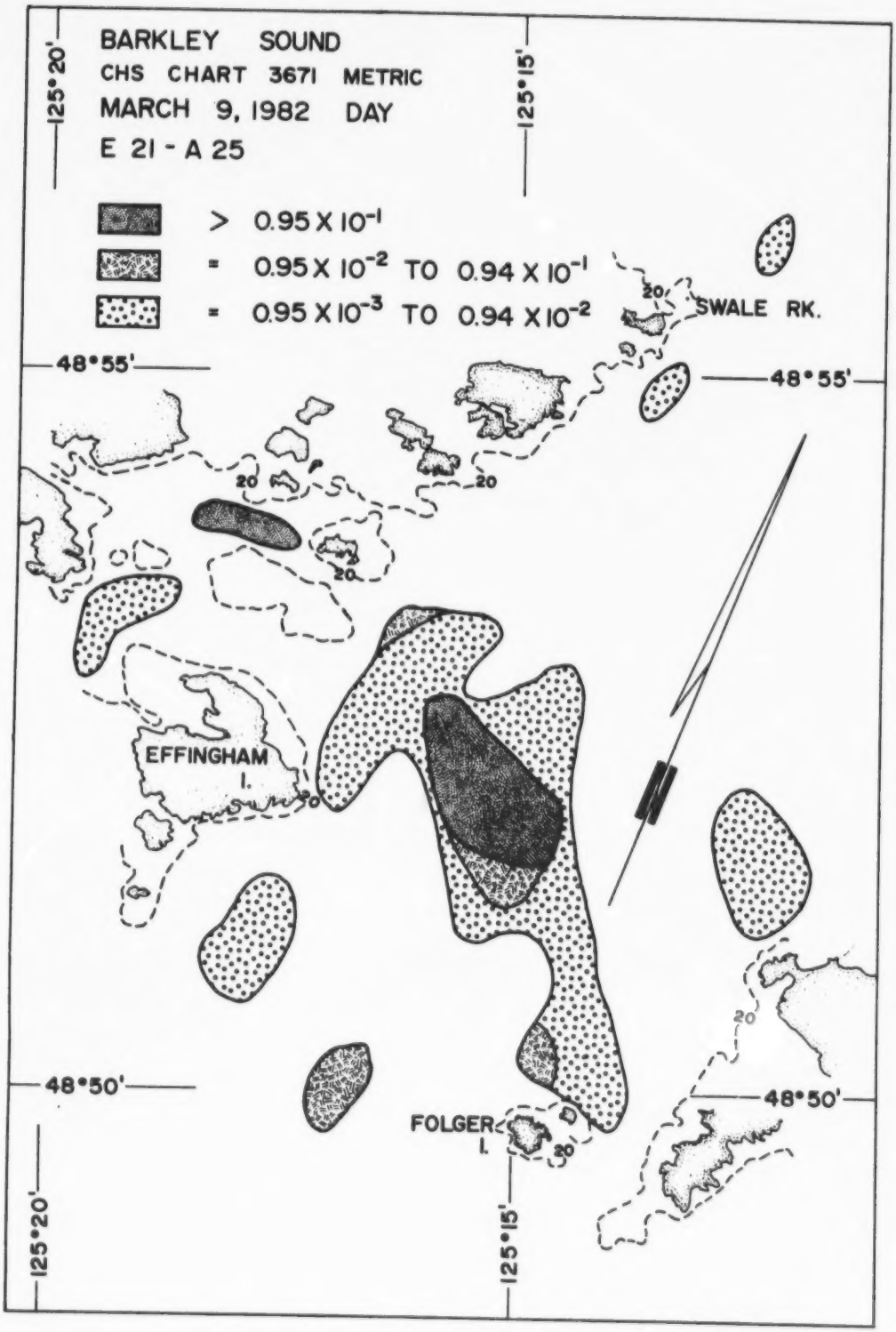


Fig. 16. Distribution of herring biomass by day, Barkley Sound, March 9, 1982.

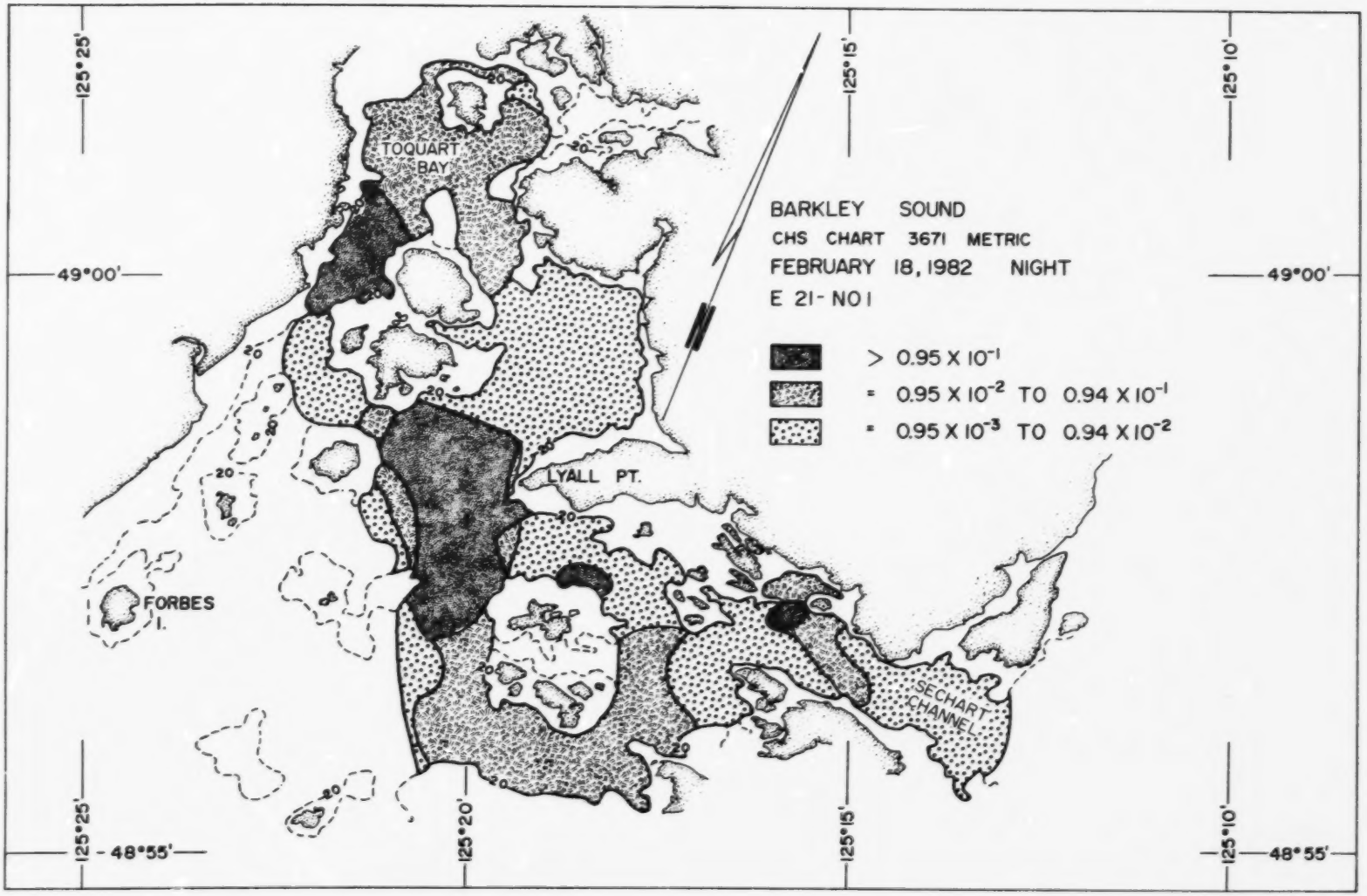


Fig. 17. Distribution of herring biomass by night, Barkley Sound, February 18, 1982.

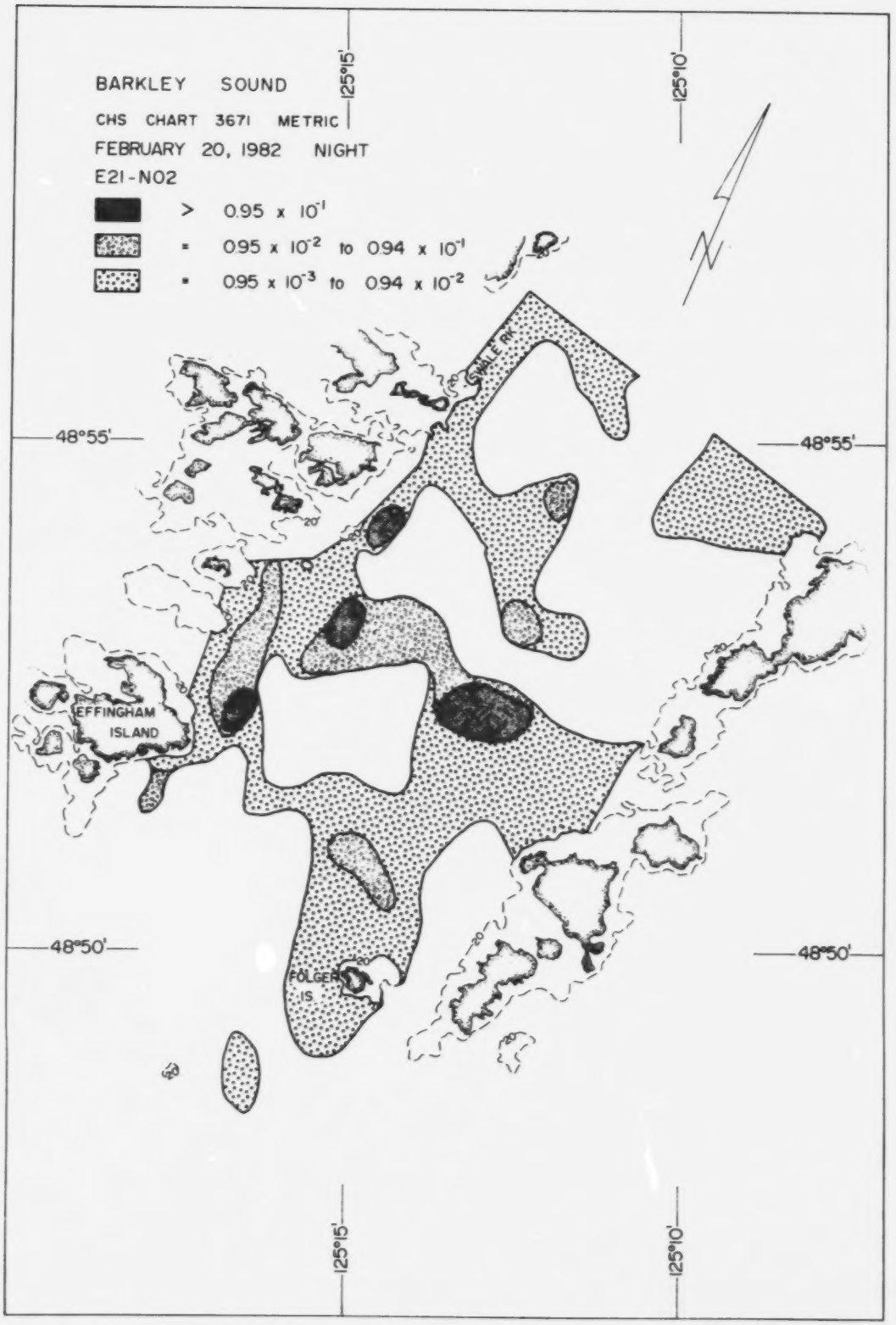


Fig. 18. Distribution of herring biomass by night, Barkley Sound, February 20, 1982.

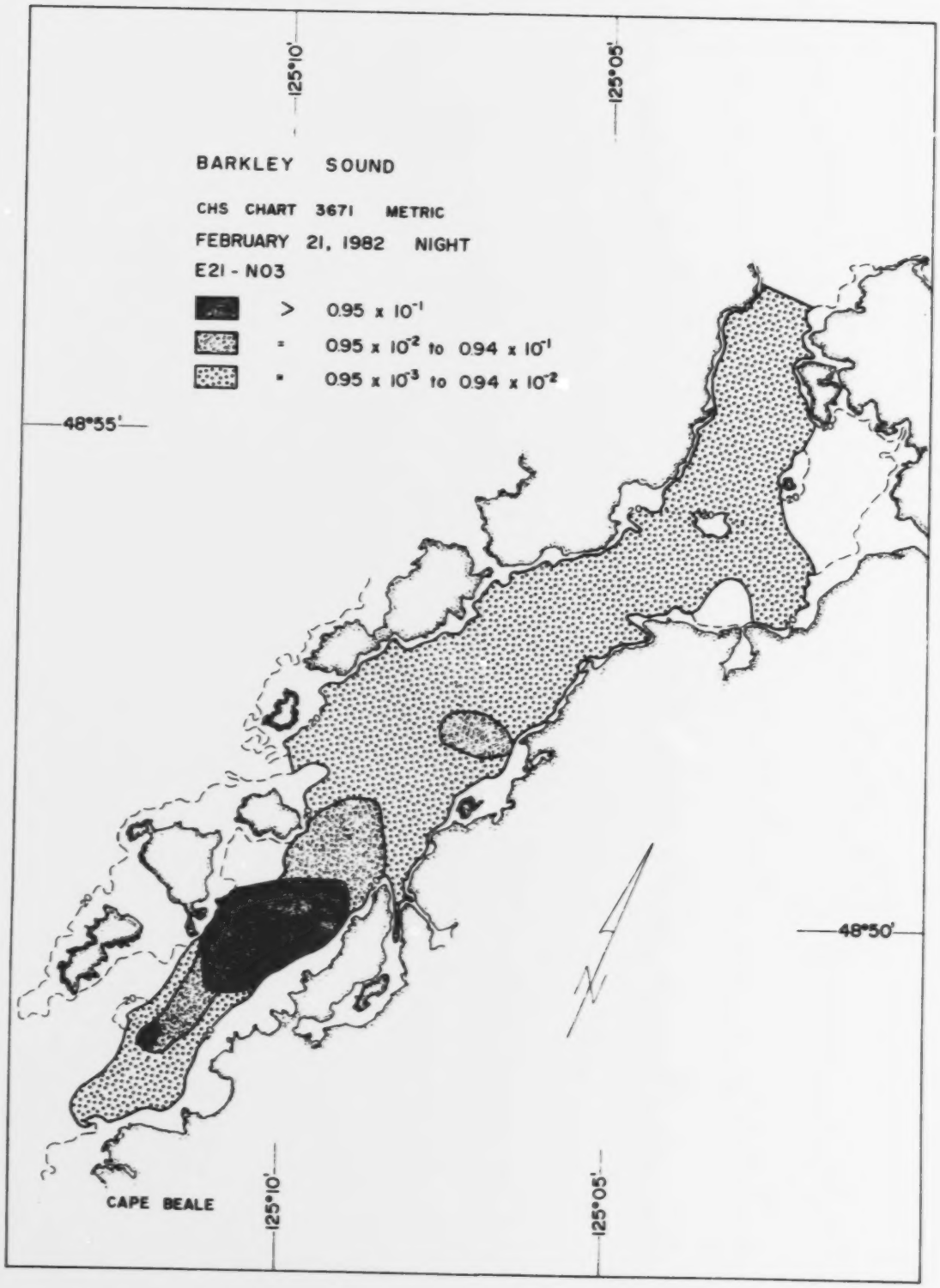


Fig. 19. Distribution of herring biomass by night, Barkley Sound, February 21, 1982.

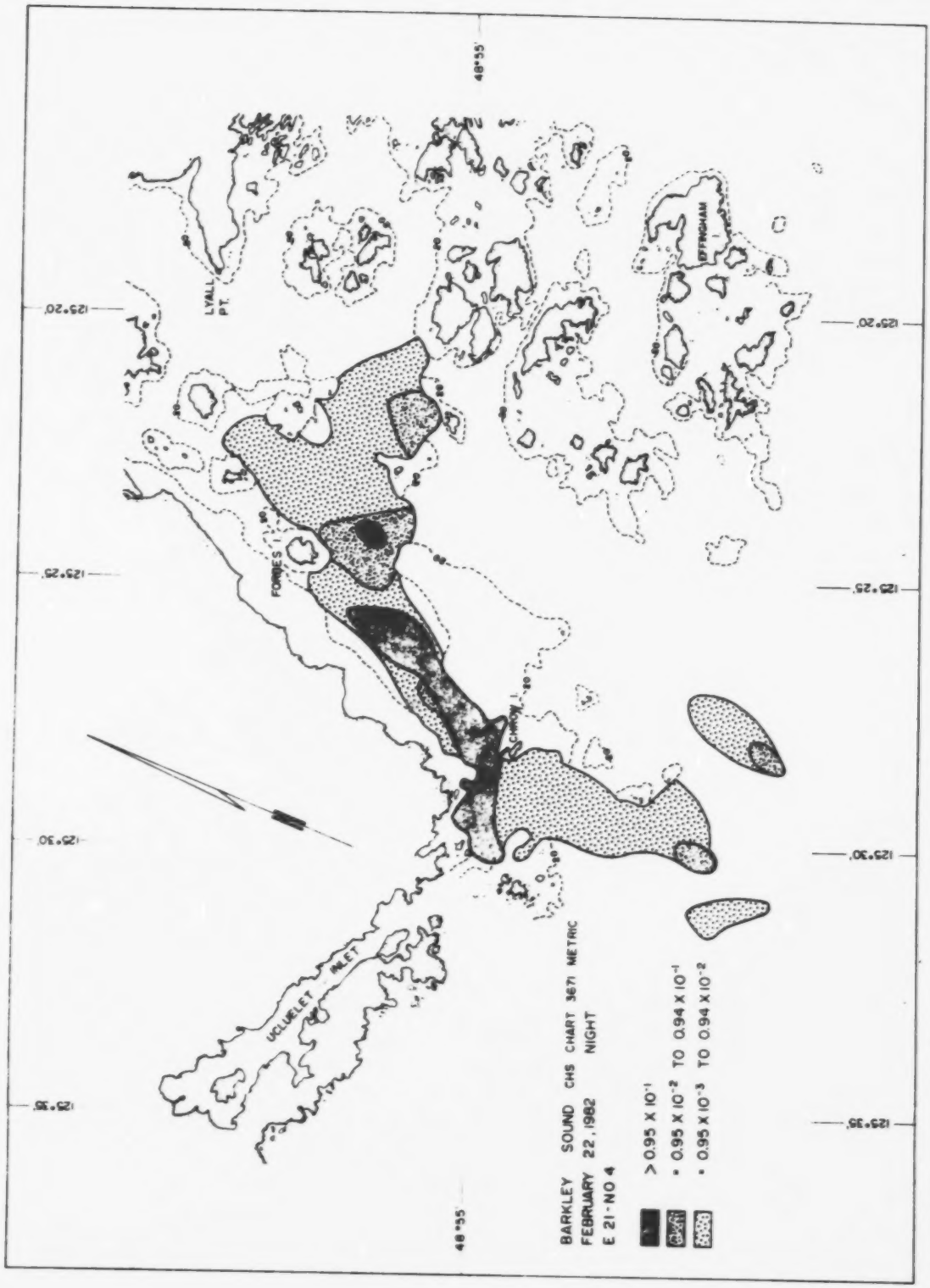


Fig. 20. Distribution of herring biomass by night, Barkley Sound, February 22, 1982.

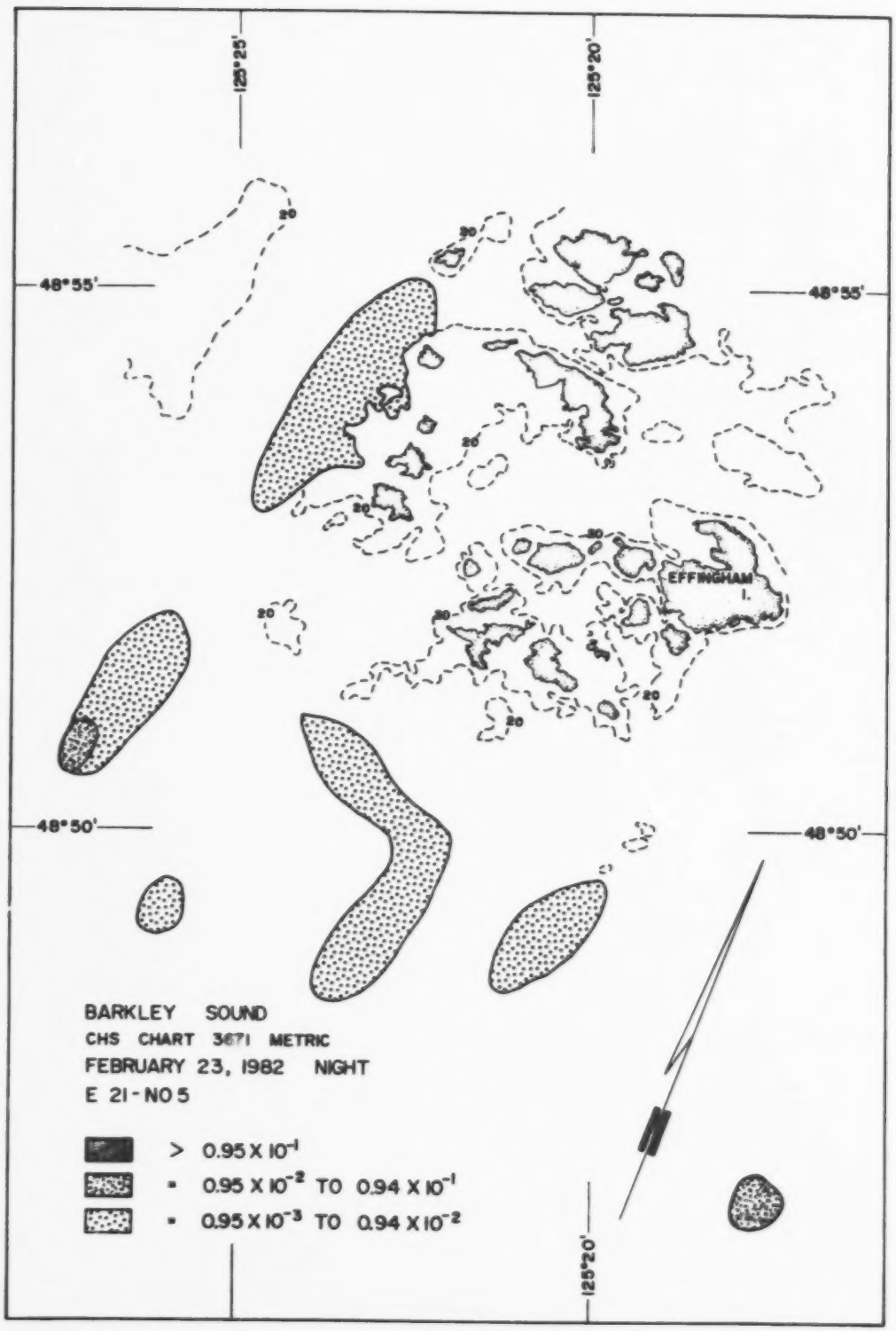


Fig. 21. Distribution of herring biomass by night, Barkley Sound, February 23, 1982.

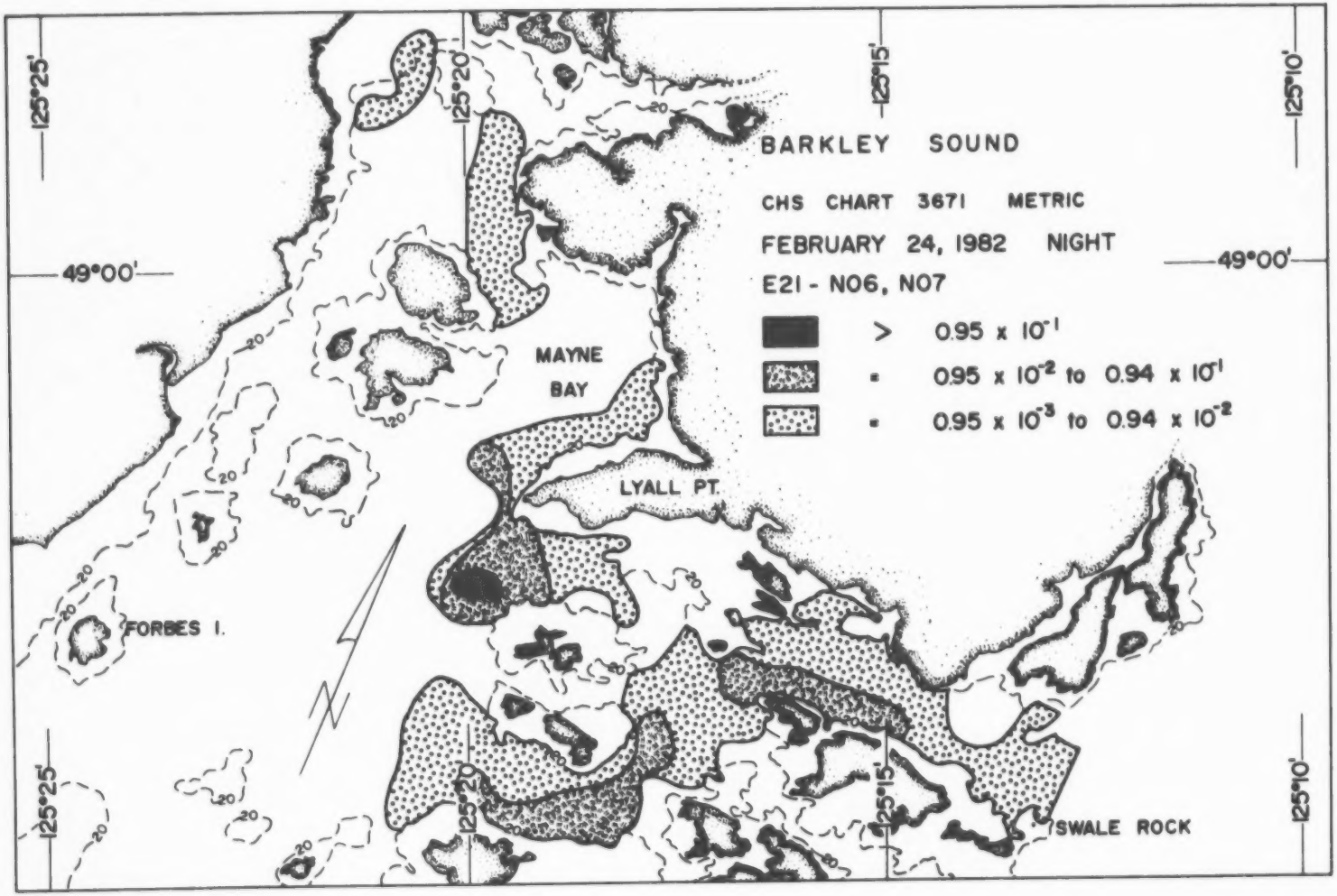


Fig. 22. Distribution of herring biomass by night, Barkley Sound, February 24, 1982.

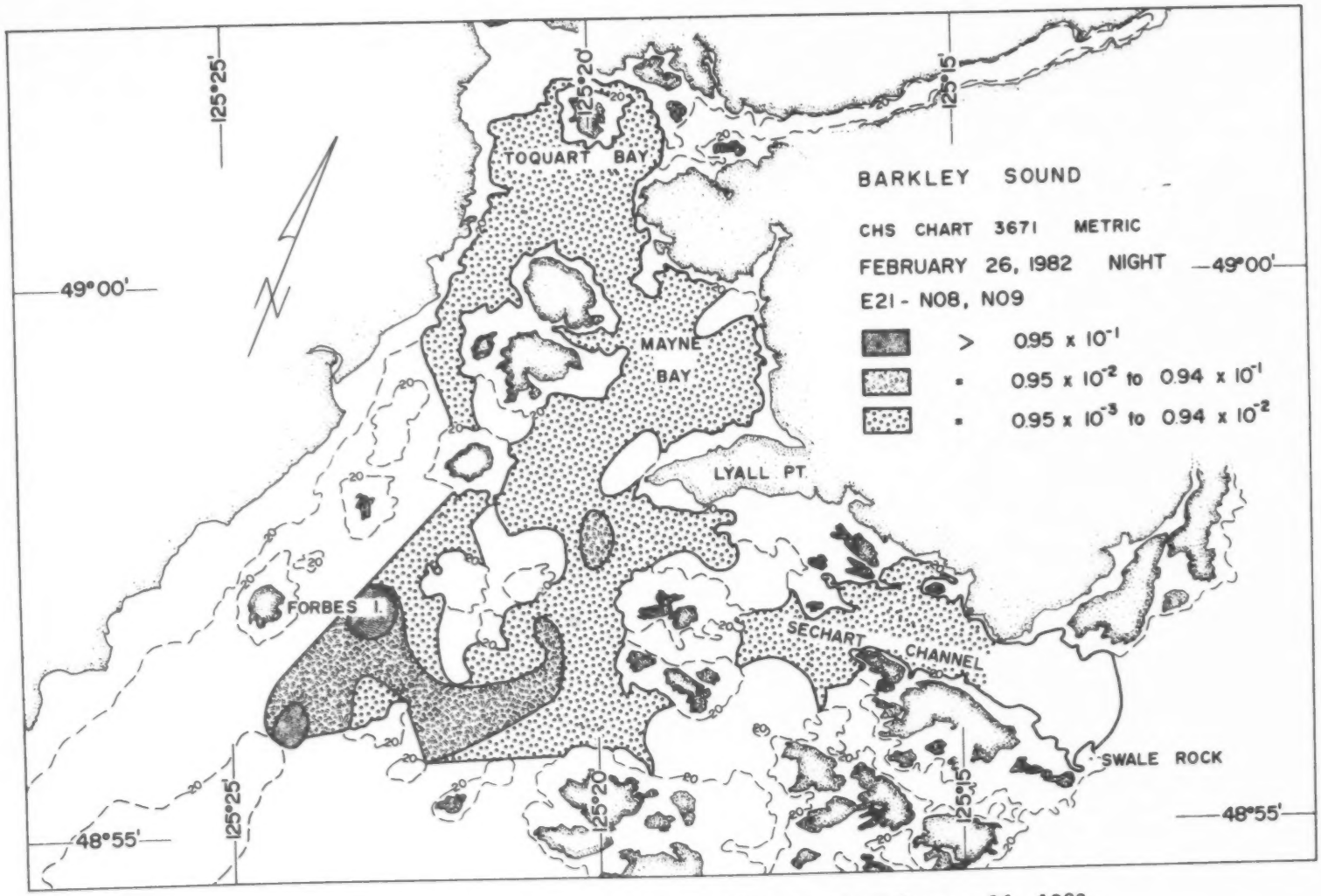


Fig. 23. Distribution of herring biomass by night, Barkley Sound, February 26, 1982.

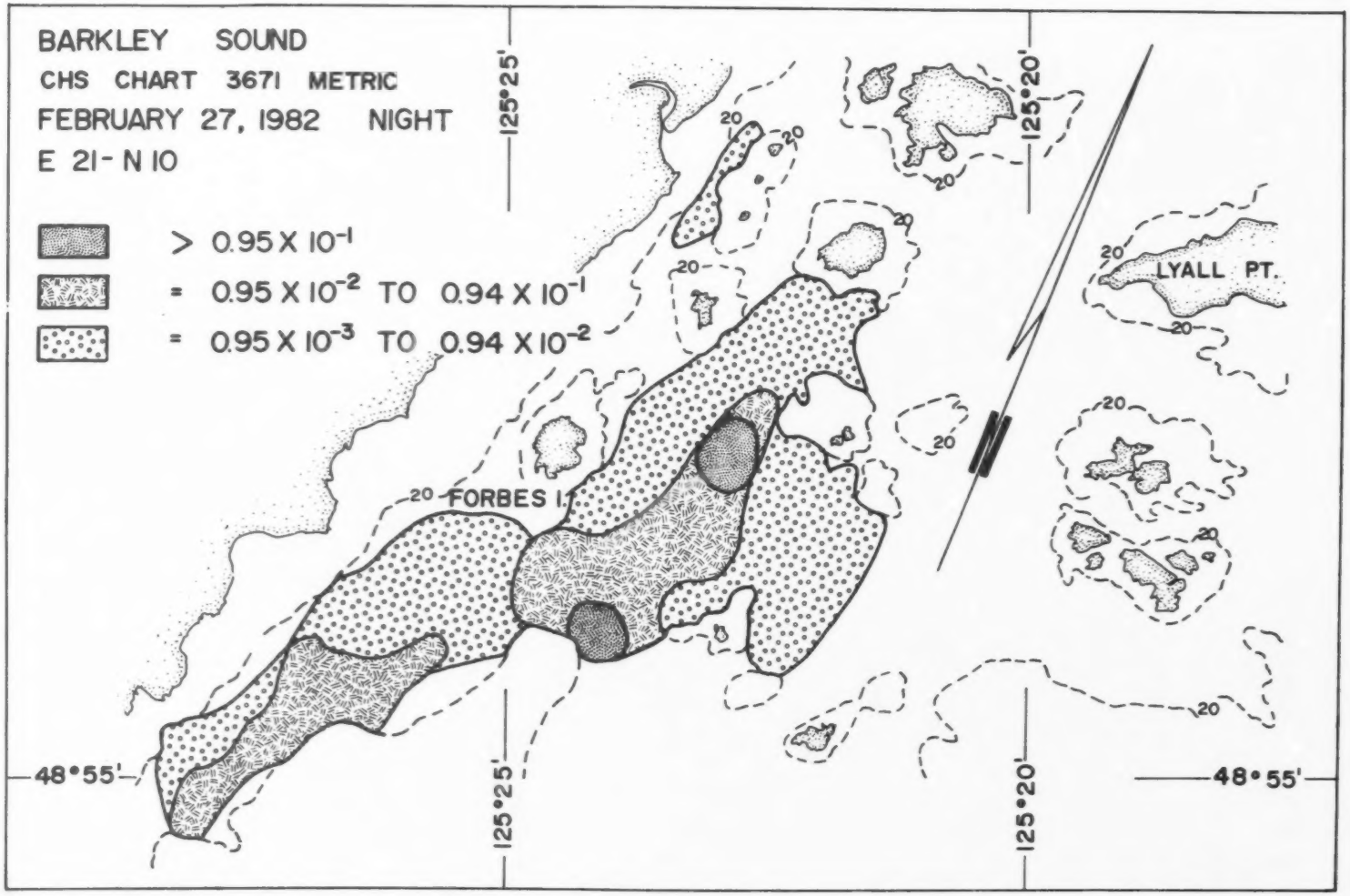


Fig. 24. Distribution of herring biomass by night, Barkley Sound, February 27, 1982.

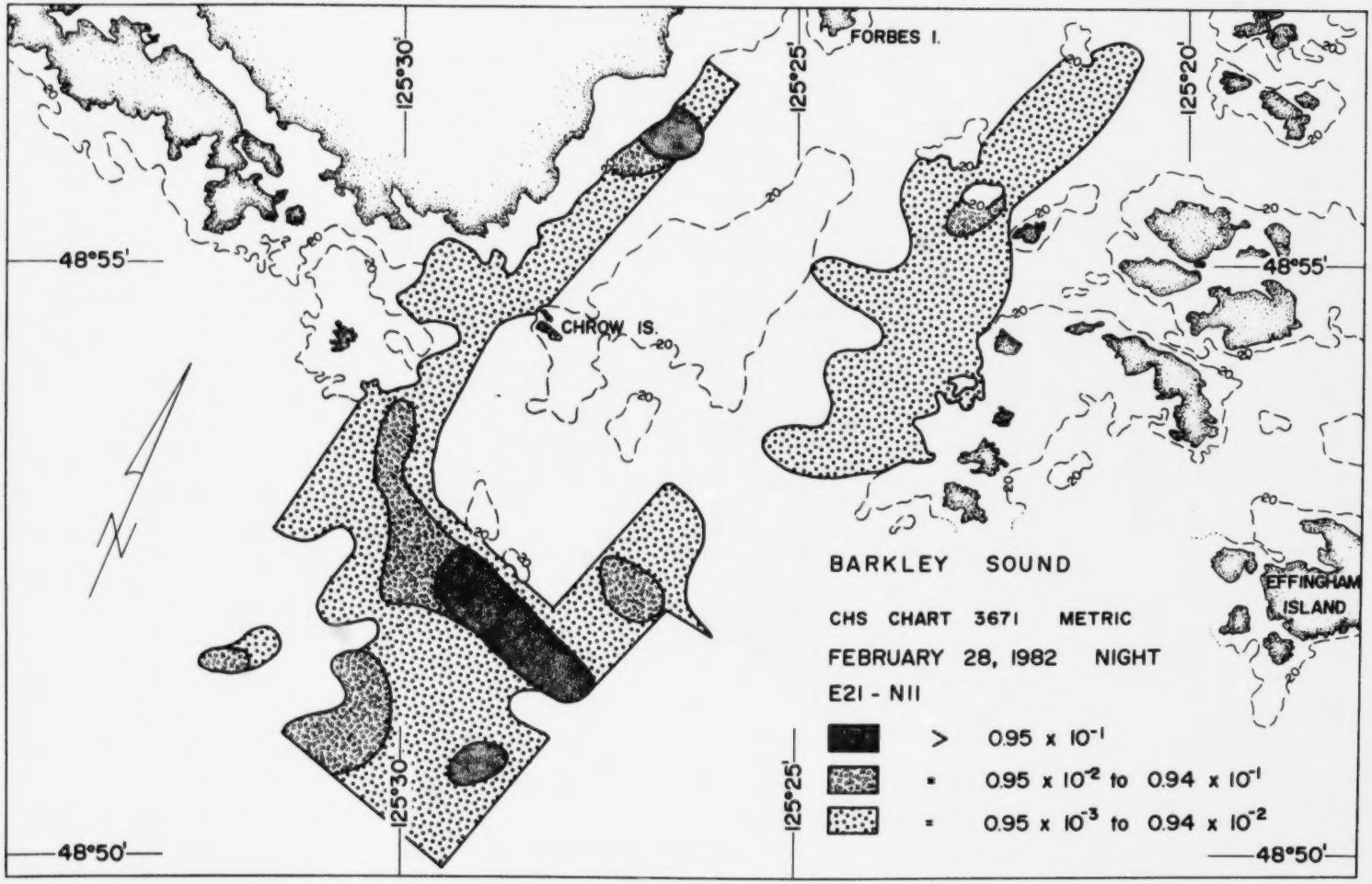


Fig. 25. Distribution of herring biomass by night, Barkley Sound, February 28, 1982.

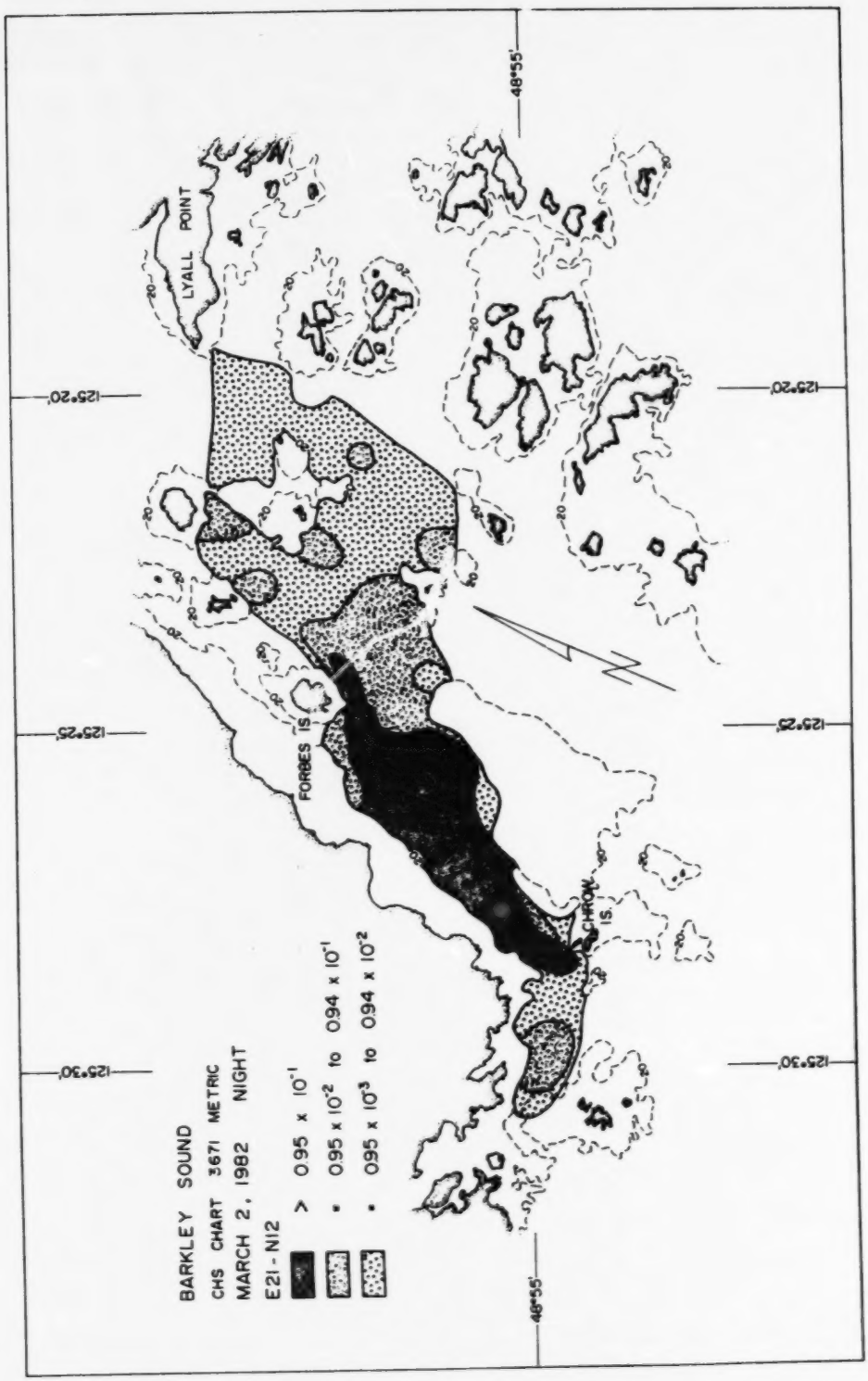


Fig. 26. Distribution of herring biomass by night, Barkley Sound, March 2, 1982.

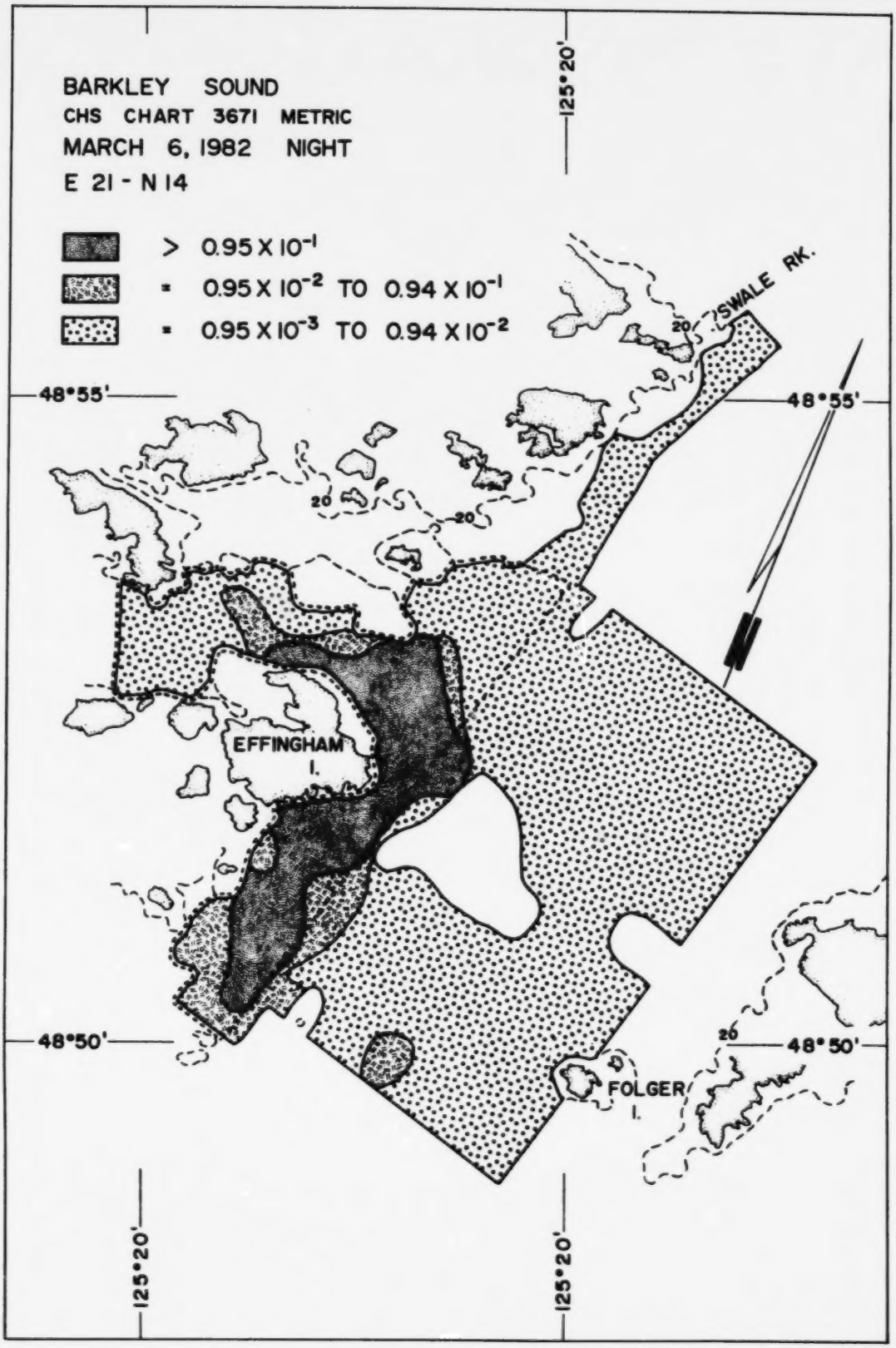


Fig. 27. Distribution of herring biomass by night, Barkley Sound, March 6, 1982.

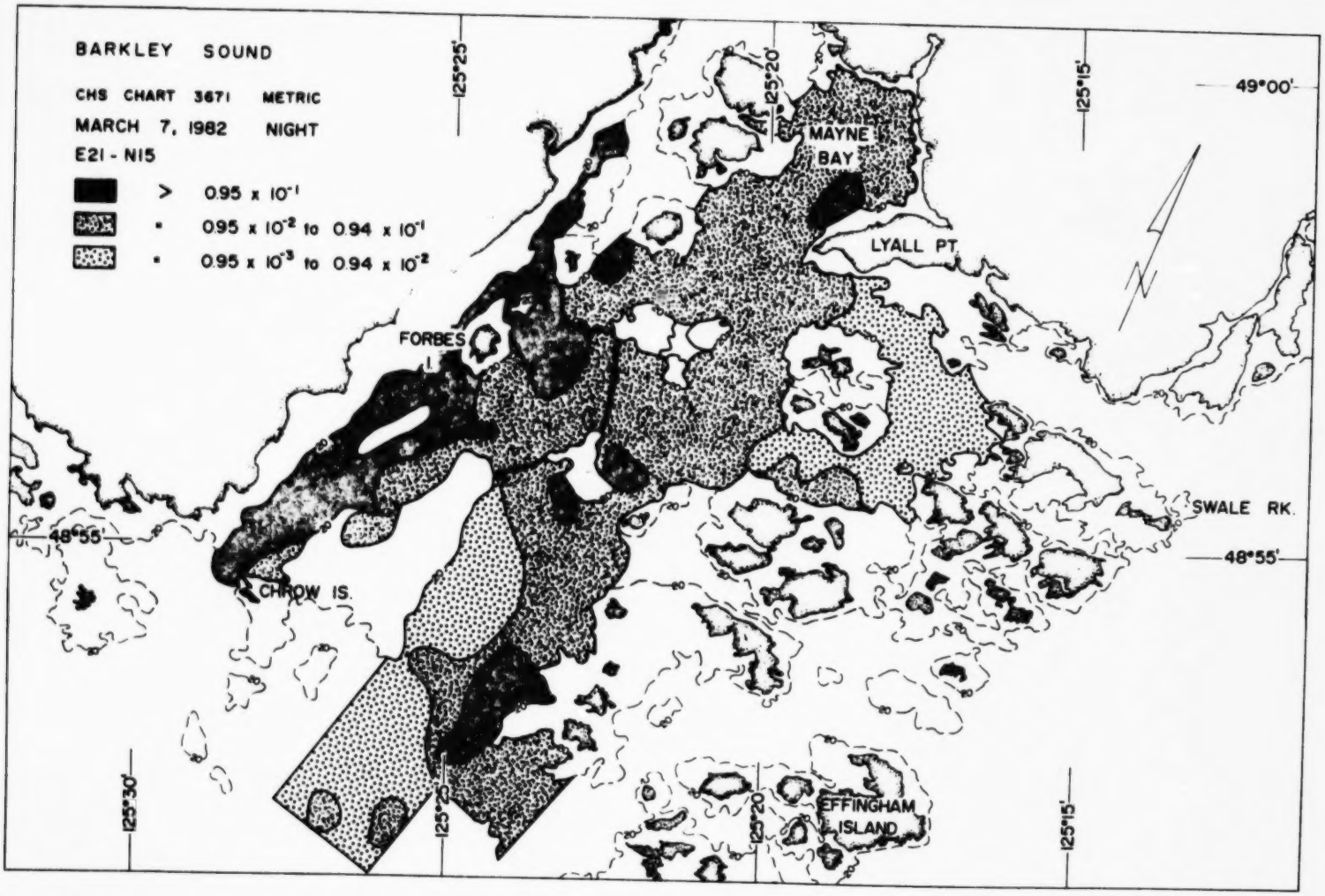


Fig. 28. Distribution of herring biomass by night, Barkley Sound, March 7, 1982.

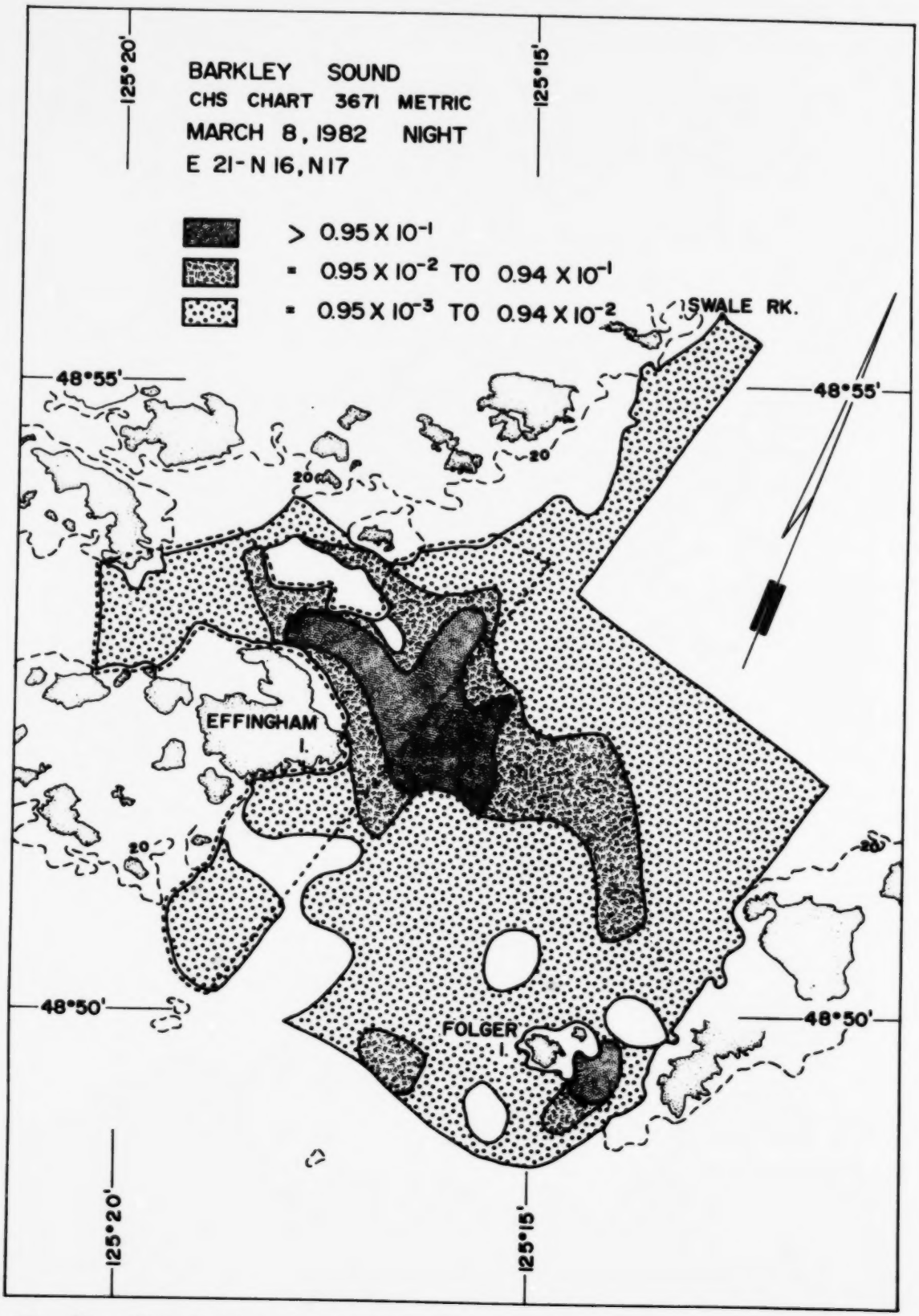


Fig. 29. Distribution of herring biomass by night, Barkley Sound, March 7, 1982.

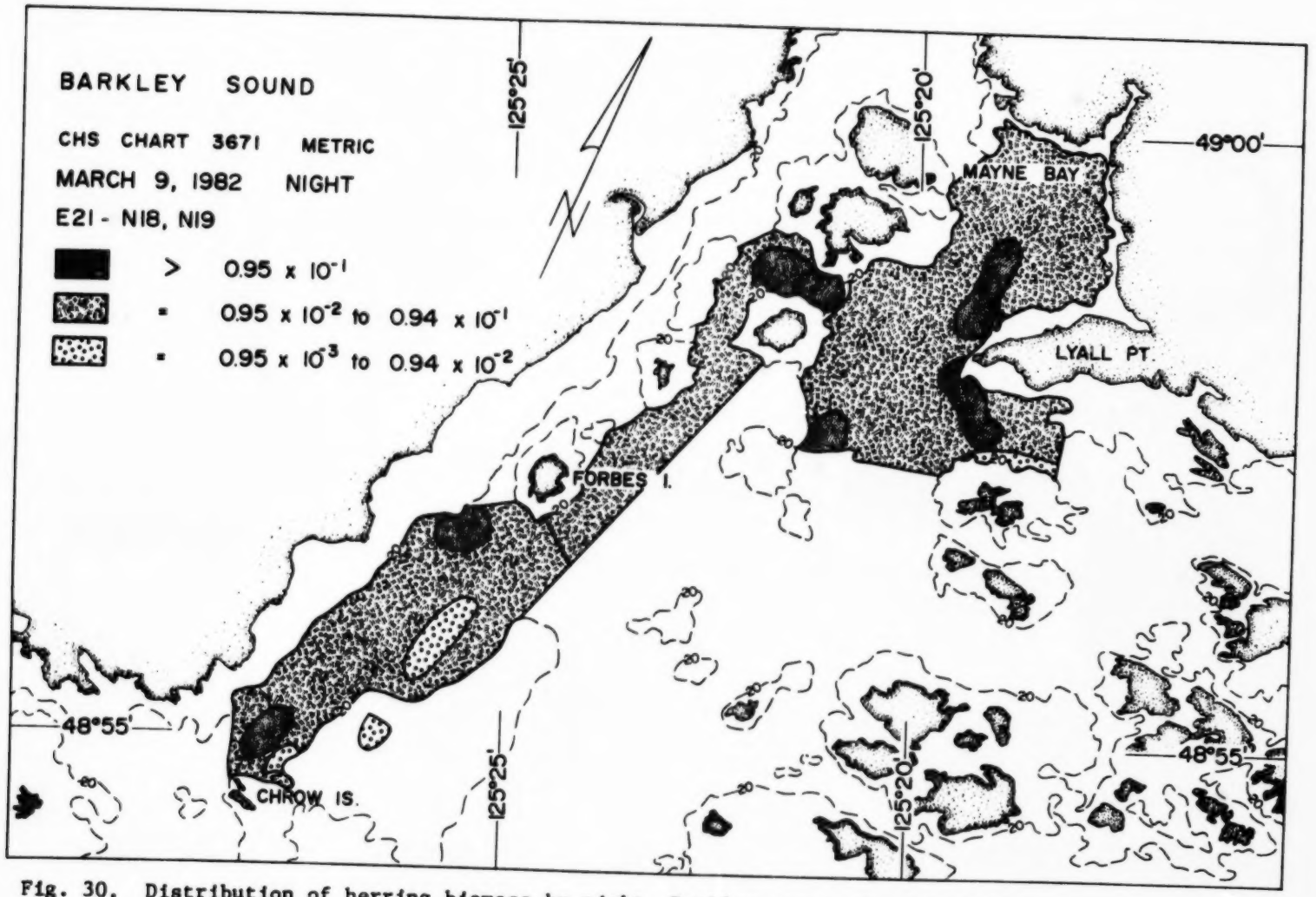
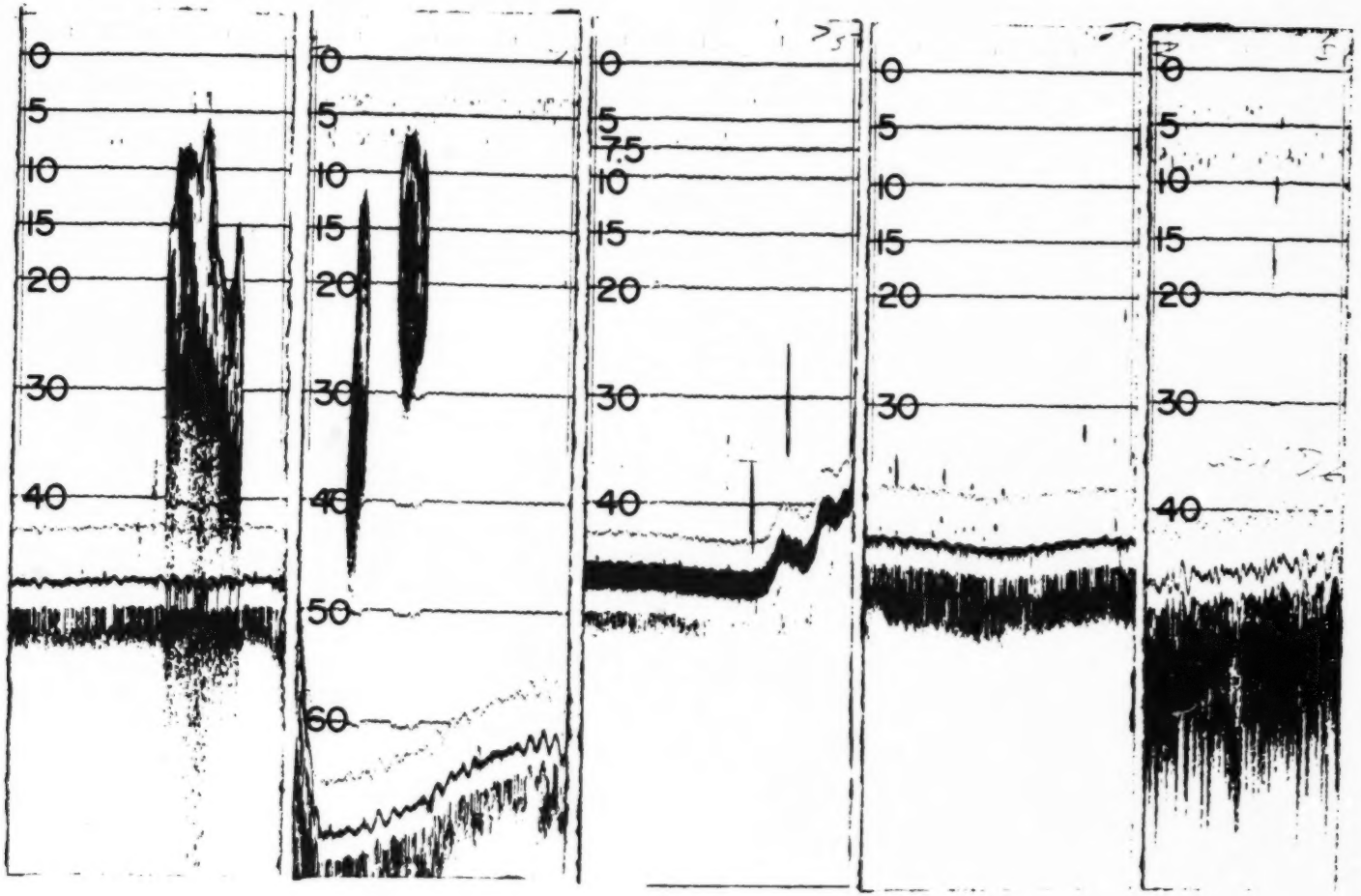


Fig. 30. Distribution of herring biomass by night, Barkley Sound, March 9, 1982.

Fig. 31A-E. Daytime herring schools of various densities, Barkley Sound, February 18 to March, 1982.

Note: Bottom tracking buffer 3-5 m above bottom and the varying thickness of the bottom trace above "white line", dependent on bottom tracking buffer delay.


0
5
10
15
20
30
40
50
60
7.5
A
0.235E+1
B
0.492E+0
C
0.493E-1
D
0.451E-2
E
0.133E-2
DAY

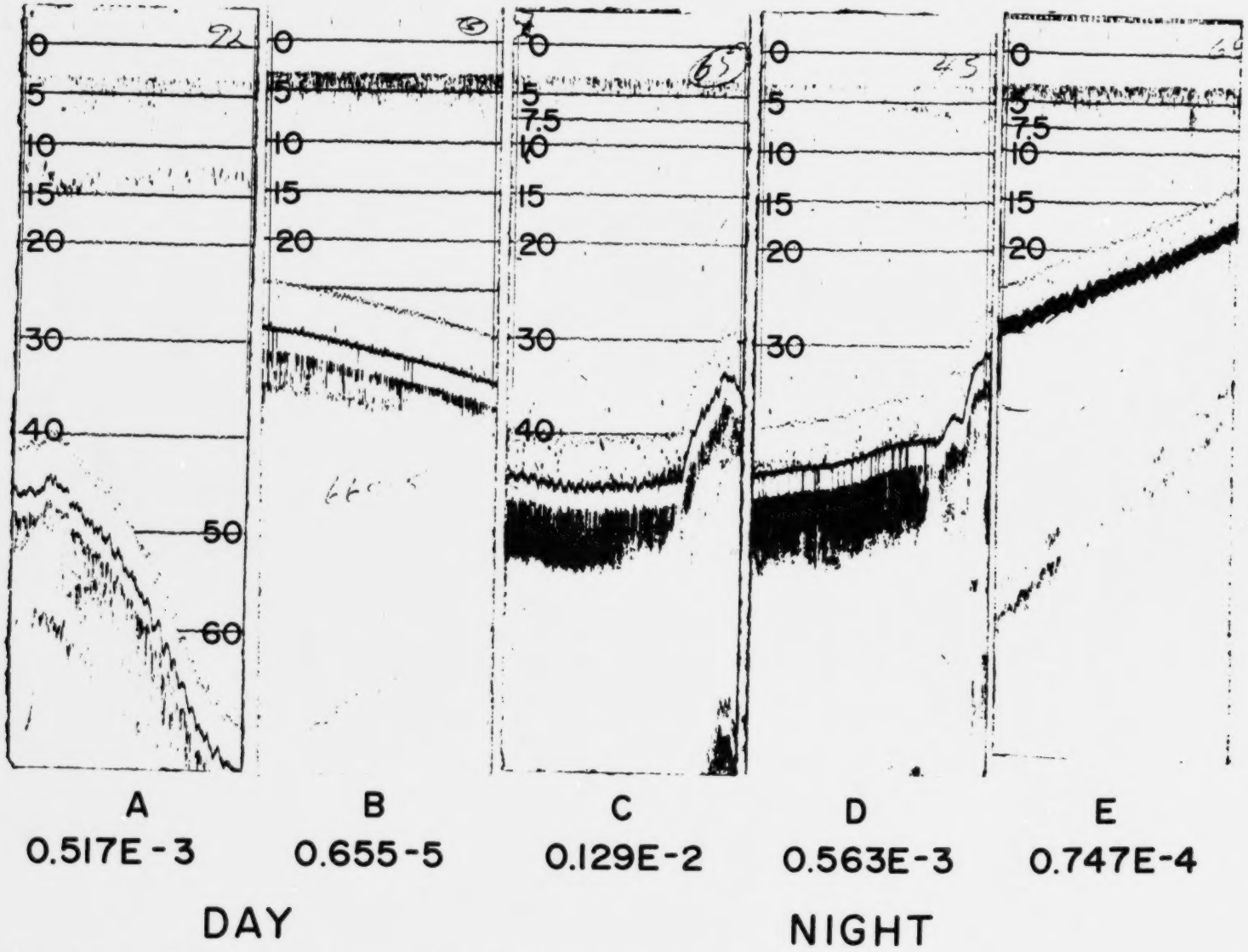


Fig. 32A-E. Examples of echosounder records with densities below threshold (0.100E-2) considered to be fish, by day (A&B) and by night (C-E) in Barkley Sound, February 18-March 12, 1982.

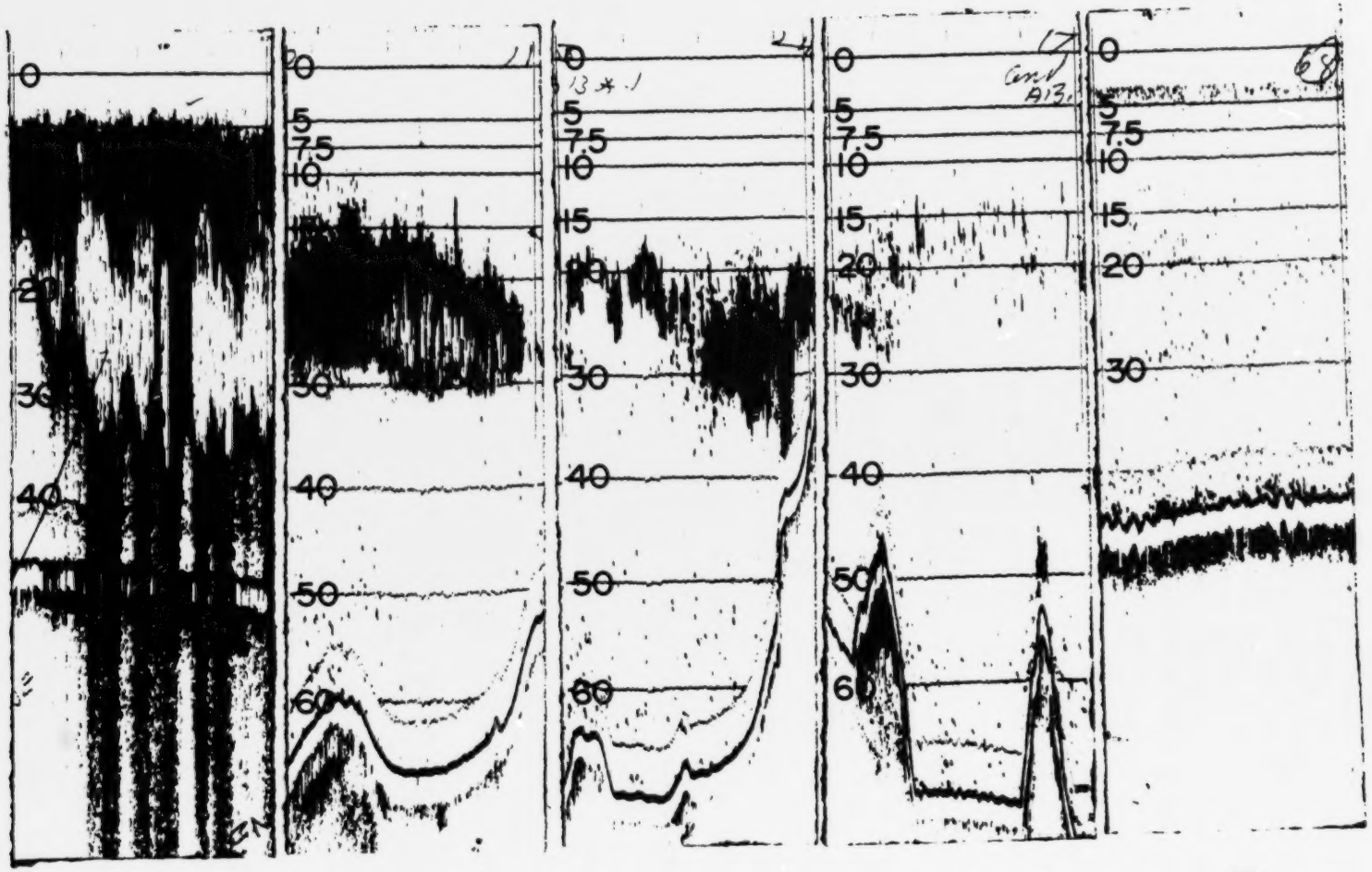


Fig. 33A-E. Nighttime herring layers of various densities, Barkley Sound, February 18-March 12, 1982.

Appendix I. Hydroacoustic system and values of constant used for biomass estimation, February 18 to March 12, 1982.

A. Hydroacoustic System

The hydroacoustic system used on the M/V EASTWARD HO in the survey of Barkley Sound from February 18 to March 12, 1982, was the same as usually used on the G.B. REED (Taylor and Kieser 1982). The system consisted of:

a) Biosonics transmitter-receiver, model 101, 38 kHz, 1000 W.

b) Simrad ceramic transducers, 38 kHz, with 15 × 30 cm radiating face giving 13° × 7° beam at 3 dB points. Serial number S4318 used in towed body. Serial number S4899 used in over-the-side mount.

c) Simrad EK38-S dry paper echo sounder recorder.

d) Ecosonics echo integrator.

e) Digital Equipment Corporation PDP11/10 computer.

f) Digital Equipment Corporation T 60 cassette unit.

g) Texas Instrument Silent 700 computer terminal.

h) Hewlett-Packard 4-channel instrumentation tape recorder model 3960 F.

i) Tektronix storage oscilloscope model RS403.

j) Fathom Oceanology towed body model 3.397-001.

k) Fabricated aluminum over-the-side transducer mounting.

l) Transducer armoured towing cable, 3 twisted shielded conductor pairs, 95 m or 15 m in length.

m) Associated custom-built units to produce calibration signals, and timing signals to chart recorder and print-out counter.

B. System Constants

The model for the hydroacoustic biomass estimation was the same as that used by Taylor and Kieser (1982). It is:

$$\overline{I}_{mn} = TL + VR + RG + SL + R100 + \overline{Y} + CTAU + BW + \overline{TS} + \overline{RO}_{mn}$$

where $\overline{I}_{mn}$ is the average intensity taken over the m depth interval and n consecutive transmissions and the terms on the right in order are:

Transmit level at one of 5 power settings, voltage response, receiver gain at one of several gain settings, shell loss on transmit and receive from towed body cover, range term, bean factor, depth slice (Δr), band width, average target strength in dB/kg and average fish density. All terms are in decibels. The values of the above constants are given below for each transducer and cable combination used.

1. Transducer 2 (serial no. S4318) with 800 ft (244 m) towing cable, 15 m lead-in and 0.02 mfd matching capacitor.

   a) Source level (TL) at nominal power settings of:

   1000 W: 222.5 dBμPa/m
   500 W: 220.4 dBμPa/m
   200 W: 216.1 dBμPa/m
   100 W: 213.7 dBμPa/m
   50 W: 210.5 dBμPa/m

   b) Voltage Response (VR) = -98.68 dBV/μPa.

   c) Shell Loss (SL) = -0.6 dB

   d) Receiver Gain (RG) = -12.00 dB or -18.00 dB.

   e) Spreading and absorption loss at reference depth (100 m)
   R100 = (2α 100 + 20 log 100) = -41.98 dB.

   f) Beam factor (Ψ) = -17.55 dB.

   g) Depth slice (CTAU or ΔR):
   $10 \log \frac{CT}{2} = 10 \log \frac{1500}{2} \times 0.006 = -3.47$ dB.

   h) Band width factor (BW):
   $10 \log \frac{I_{\sim}}{\overline{I}_{\sqcap\!\sqcup}} = -0.96$ dB

2. Transducer 3 (serial no. S4899) with 15 m towing cable 10 m lead-in and 0.02 mfd matching capacitor.

   a) Source level (TL) at nominal power settings of:

   1000 W: 223.8 dBμPa/m
   500 W: 222.2 dBμPa/m
   200 W: 218.5 dBμPa/m
   100 W: 215.9 dBμPa/m
   50 W: 212.8 dBμPa/m

   b) Voltage Response: -99.3 dBV/μPa

c) Shell Loss (SL): 0 dB
no cover on side-mounted transducer.

d-h) As in 1 d-h.

3. TVG Correction Factors

The Biosonic echosounder used in the present echo integration system has an accurate TVG whose values are incorporated into the computer program. Consequently, no secondary corrections are required.

4. Target Strength Values

Our equipment cannot measure target strength in situ. The value used of -32.0 dB, rounded from -31.5 dB, was obtained from the relationship developed in Taylor and Kieser (1982) from literature values. The relationships for fish with swim bladders is:

$$TS/kg = -7.20 \log L - 36.80$$

where L is in meters.